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A SIMULATION APPROACH TO

THE DESIGN OF AN ANCILLARY

JOB LOT SYSTEM

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SUMMARY

This research has analyzed and simulated the operating characteristics of a job shop subsystem as a smaller set of a larger enterprise. The General Purpose Systems Simulator II (GPSS II) computer language was used to build a simulation model of the actual job shop system. Simulation experiments on the model provided a basis for predictive decisions on the following basic factors:

(1) Make or buy decision.

(2) Machine utilization.

(3) Priority rules.

(4) Queue distributions.

(5) Quality control.

(6) In process inventory.

(7) Efficient utilization of resources by optimal routing route.

These simulation experiments demonstrated that this model could be extended to many job shops because of the generality of the model. This model can be applied to much larger analagous systems and the computer language is adequate for these kinds of expansions.

CHAPTER I

INTRODUCTION

The specific objective of this research is to study by simulation the operating characteristics of a job shop and to develop a methodology for the design of a production job lot system. The system chosen for simulation is a peripheral job lot production subsystem of a real time operating system.

Actually the process studied was viewed as a job shop process which is more general, more common, and more important than the typically used general purpose machine shop. Hence this model can represent job-lot quantities of piece parts with sequence of machine related operations to be performed, messages to be transmitted by a communication network, or vehicles to be passed by a highway system.

For the purpose of this study, a simulation model will be developed to determine the effects of different machines and schedules on shop performance. The resultant simulation model should help in finding the most critical areas in the overall operation. From these findings adjustments can be made for a more efficient operation of the subsystem at its present capacity and projections made for increased or decreased capacity as the primary system changes.

Each job in the present subsystem is defined as unique, a specified order which may never be repeated. The dynamic pattern of the job shop system is composed of operational situations in which certain facilities or machines are available and where a number of jobs must be processed on some or all of these machines. The goal is to optimize the use of men, machines, floor space and materials to effectively process the jobs; effectiveness being measured in terms of minimum cost, maximum profit, minimum in-process inventory, meeting due dates, etc., depending upon a particular ranking of importance.

The generality of this study is built upon the concept that most manufacturing companies have a "job shop" as a component of their total operation. Job shops may differ in size and complexity of operation, but they do have certain characteristics that identify them as a class of industrial manufacturing systems. A job shop manufacturing system is typically characterized by the physical arrangement of its equipment. The equipment is general purpose and arranged in groups according to the type of work performed in contrast to a flow shop where the machines are arranged to manufacture a specific product. These groups of similar type equipment are called machine centers and are used to process a variety of manufacturing orders. Each job order in the system is either waiting to be released or is already located at some machine center. The routing of each job order is established by a job order which involves a finite number of machine centers. The completion of a given job order involves completing the operations described on its routing sheet, each operation requiring the use of machine time at the specified machine center.

Purpose of Simulation

Simulation is defined to be an operable representation of some real world system. Shubick gives the advantages and purposes of simulation in a concise form in his definition.

> A simulation of a system or an organism is the operation of a model or simulator which is a representation of the system or organism. The model is amenable to manipulation which would be impossible, too expensive or impractical to perform on the entity it portrays. The operation of the model can be studied and, from it, properties concerning the behaviour of the actual system or its subsystem can be inferred (13).

The model or simulator in Shubick's definition can be identified as one of three types of simulation models that have been defined by Buffa (9). An Iconic model is one which actually looks like the thing it represents but which is usually scaled up or down from the original. Model airplanes and planetariums are examples of Iconic models. Analog models are models which represent something by analogy and which establish a relationship between a variable in the system and an analogous variable in the model. A graph of a firm's sales by months uses the lengths of the lines as analogous to the sales and time. The last type of model is the Symbolic model which substitutes symbols for the components of a real world system. These symbols are usually related mathematically. Symbolic simulation of realistic situations was, until recently, technologically difficult. During and after World War II, however, certain mathematical techniques were introduced that resolved technical problems which had been either too expensive to solve experimentally or too complex for analytical treatment. And, in the past twenty years, the art of simulation has expanded to include experimentation on the digital computer in many other fields.

Until the advent of electronic data processing equipment, the computational problems related to job shop manufacturing systems presented such an overwhelming obstacle that only heuristic methods were the basis for most analytical work done in this area. However, the economic feasibility of improved computers has expanded this area. From their very beginning, job shop operations have always received considerable importance, but not until the past two decades has there been a method of analysis which could readily handle the immense computational problems associated with them.

The exact approaches (complete enumeration and integer programming, etc.) for solving the job shop scheduling problem have met with limited success. The most prominent difficulty encountered by the exact algorithms is that the computational difficulties tend to increase rapidly with the size of the problem. Lacking a practical algorithm to solve for the exact optimum schedule for the processing of many jobs through a given set of machines, one must rely upon simulation techniques. Simulation of a job shop is a computer program that produces a schedule by the use of a criteria for optimality.

Generally, simulation studies are used to evaluate the effects of some priority rule. The concept of job or operation priority is inherent in many schedule generation procedures. A priority is simply a numerical attribute of a job or operation on which selection is based. For example, the first come first served rule says to select that job which was first to arrive in the queue. A countless number of such rules can be formulated, depending upon the objectives of the operation. A priority system must always have sufficient precision to lead to a unique selection so that two competing jobs should never have precisely the same value of priority. This may require that in support of the primary priority attribute there may be secondary attributes assumed in order to resolve ties.

Since the priorities would be small integers, one would expect frequent ties and the job identification number might be arbitrarily specified as the secondary priority attribute, so that between two jobs with an equal number of operations, the job with the smaller identification number is selected first.

Study Procedure

This study encompasses all printing matter required by Delta which came from all the various departments of the company and focuses on the printing section in its role as a supplier of this printed matter. This study will also include a feasibility of getting jobs which are presently done by outside vendors within the printing section itself with some increased equipment and labor if necessary.

The following procedures will be utilized in preparing this study:

(1) Each source of printed matter considered will be of any one of the following categories:

(a) Repetitive Jobs: These jobs are repeated after a certain period of time. In most cases a single master plate is made and is reused. The master plate made is a metal one because it can be stored for a long period of time.

(b) Similar Jobs: These jobs are similar to one or more of the jobs processed earlier. In all these cases, a new master plate is made.

(c) Unique Jobs: Each job is unique, a specified quantity made to special customer order which may never be repeated. Because of the uniqueness of the jobs a new master plate is made for each job.

(2) The process will be viewed as a job shop process. Basically, a job shop consists of a variety of facilities or machines through which pass each job. Production is in lots of a specified quantity. The variety of jobs competing

for the same common facilities at the same time generates the scheduling, queueing, quality control and cost problems.

(3) Cost and volume information was obtained from personnel responsible for the various sources, accounting records, and from previous studies in the company.

(4) Personal interviews were conducted with the printing section personnel and the various other departments using printings and other source's services. A complete flow of the printing process was outlined by the printing section manager.

(5) The operating process and historical input of the printing section were used to determine the distribution of job set up times as well as processing times.

(6) Analysis of the printing job orders for the period July 1968 until June 1969 provided the source document for data concerning size, quality and due date.

(7) The future printing needs of company will be forecast. These may be in terms of additional and/or improved sources for printing.

(8) The most efficient utilization of the present equipment and the company's future growth will be taken into account for meeting the printing requirements.

Factors to be Considered

The printing section will accept all printing or reproduction requests unless one of the following conditions exist.

(1) Accomplishment

The master document is larger than 14.4 x 20.5 inches or the copy size is larger than 14 x 20 inches (since the present equipment cannot handle large sizes). Sometimes jobs require specialized press or finishing equipment (carbon snap out, continuous run form, etc.). These jobs cannot be done because of insufficient machinery.

(2) Quality Factor

Quality printing is a matter of design, copy--preparation, camera work, paper and ink solution. All of the above factors enter into the quality of the finished job. Delta at present does not have sophisticated machinery designed to do color process printing, hence it makes use of commerical printing companies which have presses specially to do color process printing.

(3) Time Factor

The manufacturing interval (defined as the total time job is in the printing shop) is relatively long, which causes them to resort to rush activities a great deal of the time to expedite the movement of urgently needed jobs. The printing section does not have the press or finishing capacity to complete a job by its due date, a later date cannot be acceptable and the job does not have enough priority to displace any jobs currently scheduled or in production.

(4) Cost Factor

The shop usually experiences both overtime and idle time expenses. This is due to unbalances of the loads on the different machines which results in one operation being overloaded with work resulting in overtime, while another operation is starving for work, and experiencing idle time. Some jobs can be printed outside at a lower cost due to the specific design of these commercial printing presses.

Upon arrival of an order, the printing section makes a decision whether to accept or reject it in light of the size, quality, accomplishment, and cost. Once the job is accepted a crude estimate is made of the processing times of the jobs at various machines. If accepted, a due date is normally set according to the customers requirements. The customers requirements are transformed by the printing section into a set of structural properties, laid down in product specifications (master plates, specifications for material, quality, size etc.). In order to find out what has to be printed, the inventory of materials is checked, and it is determined furthermore what to procure from outside the company. For the jobs to be printed, the process specifications are then determined, which involves identification of the operations, their technological ordering, and the estimated processing time at the capable machines. Then either a schedule is made, thereby the time for dispatching is calculated, or the job enters the printing shop immediately after a priority has been assigned to the job or individual operation.

It must, however, be remembered here that only the most important function of printing will be discussed here. Such functions as the procurement of raw materials or the hiring and training of the skilled labor force do in fact influence the scheduling. But, as will become evident in the literature survey, these give rise to more complex problems, that further complications will make significant results even more distant from reality.

Thus the printing shop scheduling is not merely a question of performing

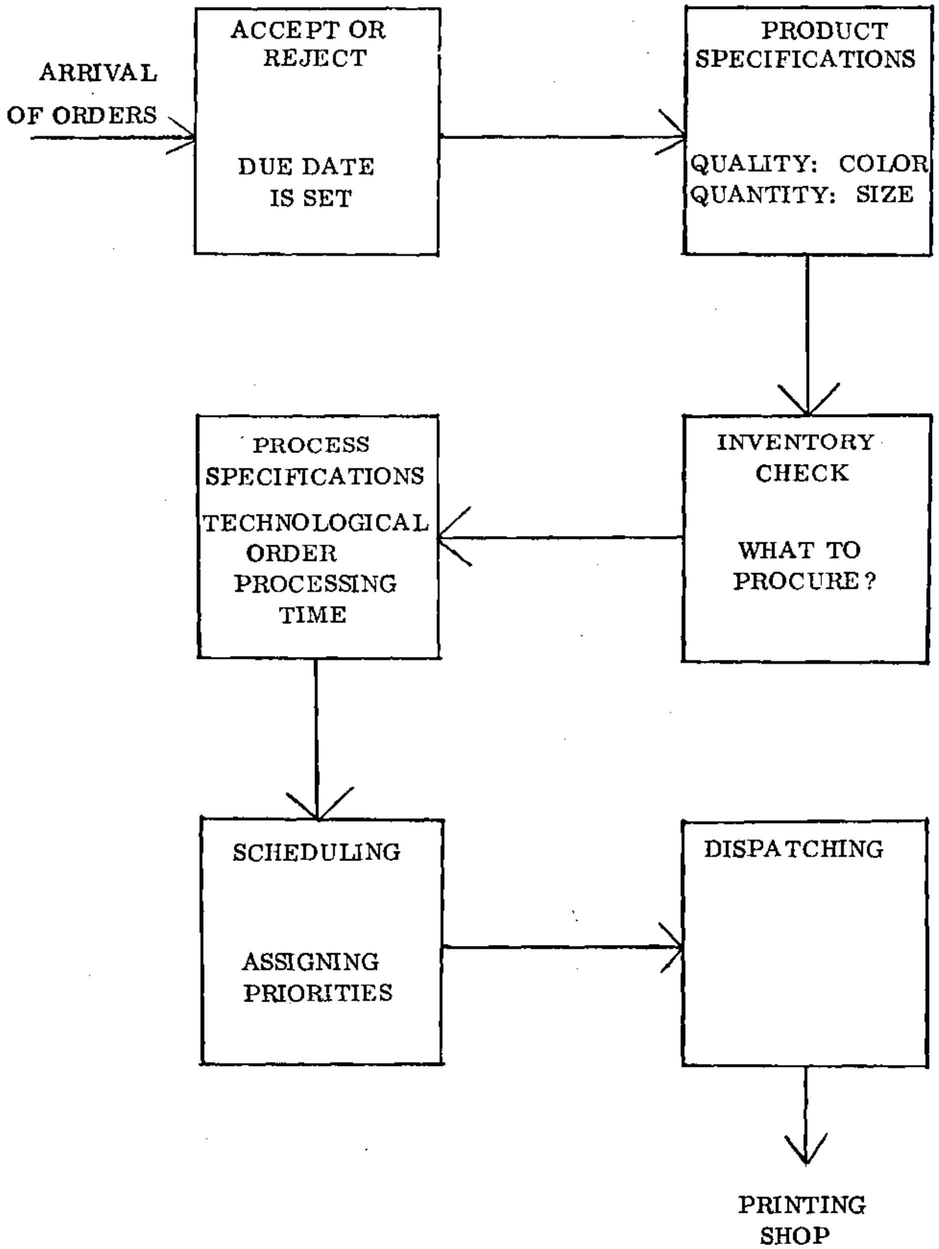


Figure 1. Administrative Steps Before the Printing.

a large number of independent functions. They are highly inter-related and vary with respect to their scope and to the skills required to carry them out. The printing section management faces the problem of planning the manufacturing facilities (number and type of new machines to acquire). The printing section has the option of influencing either the number and types of jobs that arrive at the shop, or the capability of the machines or both. Whichever option is adopted, the management is faced with the problem of matching the incoming rate and technology of the jobs arriving at the shop with the capability of the machines. This long term problem should be addressed to the management because it involves the future structure of the whole printing shop. Another problem is that of fixing the due dates. This decision is ordinarily made by the department sending in their jobs for printing. This decision must be based viewing the present and future loads of the printing shop. Since the printing shop is committed to deliver the job on (or before) the due date, the departments sending the jobs have a great influence on the scheduling problems that the printing section encounters in its attempt to meet the due date. The departments requesting jobs to be done want fast service which will be in conflict with the objectives of the printing section whose interests are to minimize production costs and hence, keep the rush orders down. This problem, therefore, should be taken up by a higher managerial level which includes the interests of both the departments sending the jobs and those of the printing section.

Once this problem is solved then only will the printing section be able to formulate a method of setting due dates. However, here we shall set the priority according to the due dates set by the departments sending the jobs.

This research presents an economic and simple simulator system designed to meet the long range planning needs of Delta's Printing Section. The system provides a simulation of future load and utilization for each machine in the printing shop. With such information, Delta can confidently and thoroughly plan for the future.

CHAPTER II

LITERATURE SURVEY

The earliest scheduling was done by means of Gantt charts. The Gantt charts were developed by Henry L. Gantt circa, 1914. Since that time Gantt methods and charts have become widely known and used in all industrial countries.

A Gantt chart is a chart on which each facility is represented by a horizontal line, the so called time axis. Operation times and idle times are indicated on these horizontal lines. Vertically are listed the kinds of facilities to which the various requirements must be allocated to which capacity are to be apportioned. This allocation is accomplished by assigning the time necessary for performance of the given tasks to the available capacities or requirements by trial and error until some feasible fit is discovered. A Gantt chart for the case of three facilities and three jobs is shown in Figure 2.

This Gantt chart provides the following information:

(1) Job 1 is first processed on facility 1, next on facility 2, and finally on facility 3.

(2) Job 2 is first processed on facility 2, next on facility 1, and finally on facility 3.

(3) Job 3 is first processed on facility 3, then on facility 2, and finally on facility 1.

Hence the Gantt chart indicates the routing of a job.

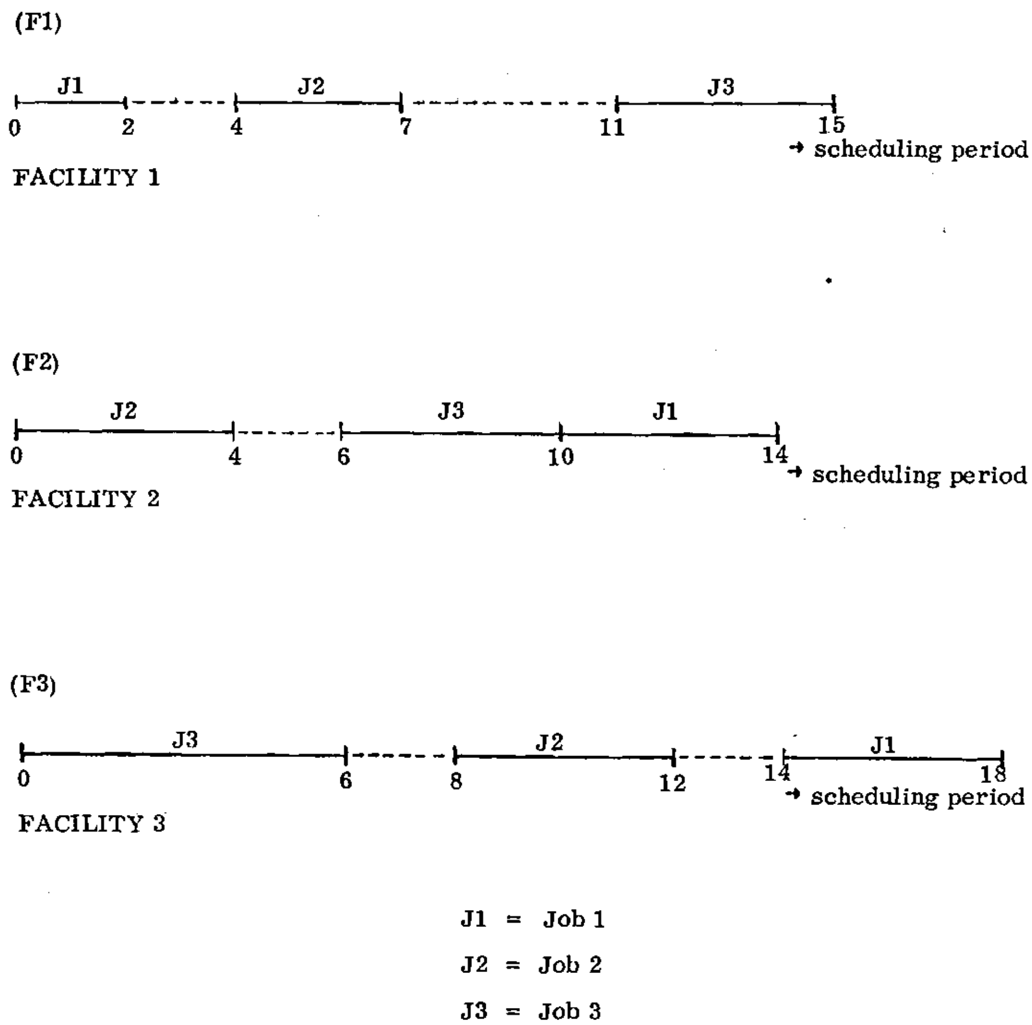


Figure 2. A Gantt Chart.

r1 = routing of job 1 (1,2,3)
r2 = routing of job 2(2,1,3)
r3 = routing of job 3 (3,2,1)

The Gantt chart is still in extensive use in industry and is reasonably effective in small, relatively uncomplicated scheduling situations.

The Gantt chart has certain limitations. Such charts work best in situations where the detail is broad enough that frequent internal change affect the total picture slightly. Its other limitation is its inability to pinpoint clearly interferences in project scheduling due to sequencing restrictions. Such restrictions are very important on complex tasks. Better approach to progress control in complex projects can be accomplished by techniques popularly known as Project Evaluation and Review Techniques (PERT) and Critical Path Method (CPM).

The basis of both CPM and PERT is the project network diagram. The network is essentially an outgrowth of the Gantt or bar chart, which is primarily designed to control the time element of a program. Here the bar chart portrays the major activities comprising the program, their scheduled start and finish times, and their current status. The important ingredients added by the program network concept are that (1) the dependencies of the activities are noted explicitly, and (2) more detailed definition of activities is made.

Progress in the sequencing problem through 1961 has been summarized by Sisson (30) and more recently by Conway, Maxwell and Miller (13).

The review given here differs from Sisson's review because

a) it mentions the assumptions more specifically and

b) the advantages and disadvantages of each theory so far developed are discussed.

In most articles not enough attention has been given to assumptions. Frequently some assumptions are not stated. Assumptions usually made in sequencing problems are

(1) No facility may process more than one operation at a time.

(2) Each operation, once started, must be performed to completion.

(3) A job is an entity; that is, even though the job represents a lot of individual parts, no lot may be processed by more than one facility at a time.

(4) A known finite time is required for each operation and each operation must be completed before any operation which it must precede can begin.

(5) The time intervals for processing are independent of the order in which the operations are performed.

(6) Each job must be processed by a designated sequence of facilities, this sequence being also called "the routing" or the "technological ordering."

(7) There is only one of each type of facility.

(8) A job is processed as soon as possible subject only to routing requirements.

(9) All jobs are known and are ready to be processed before the period under consideration begins.

(10) The time required to transport jobs between facilities is negligible.

(11) In-process inventory must be allowable.

(12) Facilities never break down, capable manpower is always available.

(13) Set up times are included as part of the operation times which implies that set up is independent of the sequence of jobs on facilities.

(14) No overtime.

(15) No delays between operations.

(16) No alternate job routings.

These assumptions are listed in detail to indicate how explicitly the conditions of a problem should be defined before a conceptual model can be used. There is no theoretical limit to the complexities which can be put into such a model, but no detail can be expected to appear unless it is explicitly put in. Care must be taken that unnoticed limitations are not implicitly included in the model.

The problem of sequencing several jobs on a single facility so as to minimize maximum tardiness or to minimize the sum of completion times has been solved by Smith (31) and Jackson (21). Maximum tardiness is minimized if the jobs are arranged in increasing order of processing times. Sum of completion times is minimized if the jobs are arranged in increasing order of operation times. Except for assumptions 6, 7, 8, 10 and 16, all of the assumptions mentioned must be satisfied.

If the number of facilities is increased to two with all jobs following the same routing, and if the objective is to minimize the overall time for completion of all jobs, then a single algorithm devised by Johnson (23) will find the solution. Johnson's rule is "Select the shortest operation time." If that operation is on facility A, place that job first in the sequence, if the operation is on facility B, place that job last in the sequence. Continue this process for each job; that is, select the shortest operation time in the remaining jobs, place the job of which that operation is a part either just following the jobs set aside at the head of the list or just preceding the one's at the bottom of the list, according to whether the shortest operation is on facility A or B respectively. The final list of jobs is the sequence which will minimize the time at which the last job is completed. Johnson's rule applies also to special cases of three stage operation. Even the simple one and two facility problems have not been solved for minimization of total tardiness or for penalty cost minimization in the case where different costs are assigned to the lateness of different jobs.

Assumptions 1-16 must be satisfied. The assumption 1 implies that the relation $\mathrm{Min}[t_j, 1; t_j + 1, 2] < \mathrm{Min}[t_j + 1, 1; t_j, 2]$ is transitive tj;n = degree of completion of job j in period n.

If one wants to find a solution to a more general problem, it is of vital importance to realize what the above mentioned assumptions imply. It is only these assumptions and consequent involvements which enable Johnson to give a solution for the two facility problems.

Mitten (27) devised an algorithm for the scheduling problem involving two facilities and a finite number of commodities where all commodities follow the same routing. The objective is minimization of the overall times for completion of all jobs. The difference between Johnson's solution and the above is that items 8, 9 and 15 are not assumed. Mitten used start lag and stop lag to represent transportation times between facilities, or to represent overlapping production procedures common in engineering and construction work.

The complexity of the general problem of multi-stage processing with different routings for jobs has led researchers toward simulation techniques. The Management Science Research Project at UCLA (20, 22) has employed the SWAC computer to test several priority functions against such criteria as sum of tardiness hours.

Baker and Dzielinski of IBM (4) have simulated a job shop on the IBM 740, and Conway, Johnson, and Maxwell of Cornell (14) have programmed the IBM 650 to test various priority schemes--first come first served, sum of operation times, due dates, etc., for the dynamic problem. A more exhaustive priority rule study was made by Conway (10) at the RAND Corporation and published in a USAF sponsored project report. These simulations depict the scheduling problem as a multiple queueing problem.

Le Grande (24) made a study of different priority rules and found that the Minimum processing time per operation rule will result in the minimum orders in queue or will complete the most orders, and that Minimum slack time per operation will give the best schedule performance and giving high priority to high value jobs will give the lowest in-process inventory carrying cost. However he states, "the job shop management problem is one of balancing the cost of carrying in-process inventory, the cost of labor, the capital cost of capacity and the cost of meeting specified order completion dates. Therefore, management must decide which rule or combination of rules to use in dispatching work."

Cole and Elmaghraby (15) also developed a priority rule. It is a starting priority which gives the order or release to the shop for dispatching purposes.

The priority rule adopted is a function of the slack time and is up-dated at each status reporting period.

The rule used is

$$Pi = Di - Do - \left[\frac{Hij(k) + A(k)}{8}\right]$$

Where:

Di	=	the due date of the earliest delivery in a pool (concerned with pooling future jobs with current production until maximum capacity is used)
Do	=	current date
Hij(k)	=	the operation time in the remaining operations through which a part must pass
A(k)	=	the allowance for interference and unavoidable delays and is a function of the remaining stations in route A(k) = 12 + 8k hrs.
[ ]	=	refer to the smallest integer larger than or equal to the quantity within the brackets

Therefore, the priority indicates the order of release to the shop.

Fabrysky and Shamblin (17) developed a probability based sequencing rule. Since order flow time at the machine center is uncertain and may be described as a random variable whose gross components are move time, queue time, set up time, and process time

$$tj = .mj + qj + Sj + Pj$$

the total flow time for the i^{th} order may be expressed as:

$$Ti = \sum_{j=1}^{n} tj$$

If E [tj] = Uj and Var [tj] = σ_j^2, they state that it can be shown by the Central Limit Theorem that Ti is as asympotically normal as n increases if the following four conditions exist:

(1) The flow times at machines centers, tj, are independently distributed random variables with mean uj and variance σ_j^2

(2) The third absolute moment of tj about its mean, ρ^3, is finite for every j.

(3) If $\rho^3 = \sum_{j=1}^{n} \rho_j^3$

then

$$\lim_{n \to \infty} \rho/\sigma_i^2 = 0 \text{ where } \sigma_i^2 = \sum_{j=1}^{n} \sigma_j^2$$

(4) The expected effect of any single tj on Ti is relatively insignificant. The rule developed is:

$$Zi = \frac{(Di-C) - \sum_{j=k}^{n} \mu_j}{\left[\sum_{j=k}^{n} \sigma_j^2 \right]^{\frac{1}{2}}}$$

Where Di = due date of the i^{th} order
C = current date
Zi = standard value on the distribution of remaining flow time

This causes the allocation of scarce production time to fall to those orders which have the smallest implied probability of being completed by due date, i.e. max priority = min Zi.

Some rather safe conclusions from a consensus of the literature are summarized below.

(1) There is not now a satisfactory analytical solution to a larger scheduling problem (6). The current mathematical solutions are very restricted and

would not apply to any realistic situation unless that situation is a bottleneck of at most two machines.

(2) In simulation tests, various scheduling rules perform better than either a random or a first in first out (FIFO) method of scheduling (8).

(3) Methods which make assignments in one time period based upon expected conditions in future time periods are superior to nonpredictive methods (9).

(4) Most reported research has been in nonindustrial setting. In the few reported cases where scheduling algorithms have been implemented, improvements in plant performance are actually realized (16).

(5) Real world scheduling problems must be reduced in complexity by applying various simplifying assumptions to permit automated scheduling. Something approaching a standard set of such assumptions has evolved in the literature (8).

(6) The problem of scheduling sequencing job shops in general has been treated by Wagner (33), Bowman (8), and Manne (25). The generality of the treatment of these authors which in essence amounts to the construction of an optimal Gantt chart is paid for rather heavily in the complexity of the problem (as integer linear program) and the fact that it is not feasible to obtain schedules for any but the most trivial problems in terms of the number of products and size of the shop.

(7) Analytical approaches have been unsuccessful in solving scheduling problems of practical size, and little practical success has been achieved by

iterative approaches. The most successful approach to the scheduling problem has been the heuristic approach implemented by digital simulation (4).

(8) Conway (11) used the IBM 7090 computer to simulate large job shops with machines being the single limiting resource. By selecting processing times from exponential, rectangular and constant distributions (nondeterministic) and sequencing by seventeen basic priority rules, Conway sought to find a best heuristic decision rule to fit the model he had constructed. Conway found that the "shortest operation first" rule was best with respect to its effect on work content measures, and recommended that it be considered for job shop applications because of ease of administration and its favorable effects on

a) Minimum total completion time
b) Average total completion time
c) Average number of jobs in progress
d) Average waiting time
e) Minimum total due date slippage

(9) Mize (28) investigated multiproject scheduling problems. He investigated experimentally nine complex decision rules and three single attribute decision rules for assigning priorities to jobs with the objective of meeting due dates in organizations which have in process several simultaneous PERT projects. His conclusion was that priority should be given to that job with least float if the objective were to minimize due date slippage.

(10) Van Syke (32) used Monte Carlo methods to examine characteristics of PERT schedules and found that the PERT statistics, expected project performance time and its associated variance, are generally optimistic and pessimistic respectively.

The exact approaches (analytical methods and linear programming) for solving the job shop scheduling--sequencing problem have met with limited success. The most prominent difficulty encountered by the exact algorithms is that the computational difficulties tend to increase rapidly with the size of the problem.

Lacking a practical algorithm to solve for the exact optimum schedule for the processing of many jobs through a given set of machines, one must rely upon simulation techniques. Simulation, in the context of scheduling theory, generates and evaluates many schedules and chooses the "best schedule"; i.e. the minimum of some function of the schedule time or some other criteria for optimality.

CHAPTER III

PROCEDURE FOR SOLUTION PREDICTION

Definition of Terms

There is no set of standard terms used today in a job shop scheduling process. The terms used in the literature vary with the background and field of interest of the authors (6).

The following definition of terms will be used here:

1. MACHINE: A machine is a single physical location at which an operation or a group of operations can be performed.

2. JOB: A job is a number of units which are processed through a single machine and then from one machine to the next.

3. OPERATION: The processing of a job at a specific machine is called an operation. All the work done on the units is called a process. An operation is entirely determined by the specification of the job and the machine involved.

4. SCHEDULING PERIOD: A scheduling period is the period of time of unit length ending at a specified point in time. If the flow of time is represented by a continuous line on which the discrete set of points at which a transaction can occur is designated by numbers between 0 and T inclusive, then the scheduling periods are represented by the segments between these points.

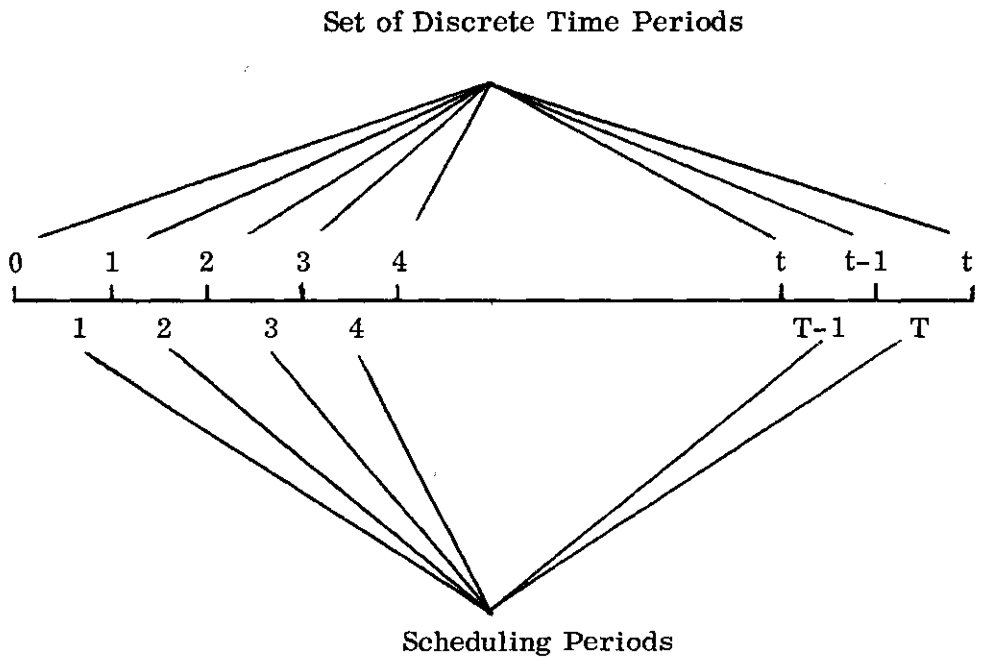


Figure 3. A Schematic Diagram Representing Scheduling Periods.

5. ROUTING: The routing of a job is the sequence of operations that must be performed on the machines in chronological order. A routing can include some; or, at most, all of the M machines. The routing of a job depends primarily on the technological requirements of the products. This information is given and forms a portion of the input information.

6. SEQUENCE: A sequence on a machine is the set of all jobs to be processed on this machine in the order in which the operations are to be performed. The sequence is hence analogous to a routing in which jobs and machines have been interchanged. A sequence provides the following information:

a) The jobs which are to be processed on the machine.
b) The order in which these jobs are to be processed.

It does not, however, provide information on the time at which the operations are performed nor on the existence of idle periods between the various operations.

7. OPERATION TIME OR PROCESSING TIME (Pt): The operation or processing time of an operation at a machine is the length of time, expressed in number of scheduling periods, that is required for the complete performance of the operation on all units of the job. It is defined as the time lapse between the beginning of the operational time until the end of the operation time.

8. SET-UP TIME (St): The set up time is defined as the time lapse between the beginning of the time available for the job on a machine until the start of an operation time. It includes all trial runs until a final full scale process can be done.

9. TRAVEL TIME (t_t): It includes the total amount of time spent by the total number of units of a job to travel from one machine to another. For larger number of units which are not transported simultaneously the estimation of travel time becomes difficult.

10. QUEUE TIME (Qt): It includes the amount of time a job waits at a machine to be processed because other jobs are ahead of it and are at present being processed on the machines.

11. TOTAL PROCESSING TIME (Tt): The total processing time is the summation of processing time, set-up time, travel time and queue time

$$Tt = Pt + St + t_t + Qt$$

Total processing time for n jobs will be

$$Tn = \sum_{t=1}^{n} T_t = \sum_{t=1}^{n} (P_t + S_t + t_t + Q_t)$$

where n refers to the total number of jobs.

12. PRINTING PLATES: Printing plates are the tools utilized to preserve the permanent copy of the master during the printing process. The four types of plates that are used are metal, itek, paper and direct impression.

a) Metal. Metal plates are used for high quantity, high quality, and multicolored work. The plates are permanent and can be reused a good number of times.

b) Itek. The Itek plates are used for good quality and medium quantity jobs.

c) Paper. Paper plates are used for low quality and low quantity jobs.

d) Direct Impressions: Direct impression plates are masters capable of being reproduced, in the state in which they exist directly on the copies by either a printing press or a Xerox machine.

13. PAPER: Paper varies in quality, size, and weight (cloth content per pound) and is utilized according to the requirements of the job. (A job requiring printing on both sides requires a heavier grade of paper, ink, etc.).

14. BINDING OPERATION: The binding operation includes collating, stapling, stitching, and folding.

15. FINISHING OPERATION: The finishing operation includes cutting and padding.

16. IMPRESSIONS: An impression is considered to be the image transferred from plate to paper sheets. Depending on the image size, the plate may contain

X number (1, 2 or multiple) impressions. Each time the plate image is offset to the sheet of paper that number X of impressions is considered to have been printed and one sheet is considered to have been used.

Plan of Attack

(1) Formulate the production service system. Identify the problem and system boundaries in order to establish the appropriate level of study.

(2) Describe the real world system to be modeled.

(3) Structure the model.

(4) Data collection; required, given, accuracy and precision of data.

(5) System behavior to be simulated through time. The model behavior is compared with the real world system.

(6) Test the solution, qualitatively as well an quantitatively. Goodness of Model. Should it be revised? Can the solution be implemented?

(7) The results of the model experiments to be related to the real world system, and their implications to be discussed.

Modeling Language

The GPSS II computer language will be used in modeling the system. The primary reason for the choice of GPSS II is its natural adaptability as a technique for the simulation study of the flow of traffic through a system. Also, the effects of competition for equipment in the system may be measured. GPSS also has the following advantages:

(1) It requires no extensive computer programming experience.

(2) The volume of traffic (jobs) flowing through sections of the system can be found.

(3) It provides the distribution of transit times for the traffic (jobs) flowing between selected points in the system.

(4) It provides the average utilization of facilities in the system.

(5) It provides the maximum and average queue lengths at selected points in the system.

(6) It is easy to debug and analyze.

(7) Results can be easily interpreted by a person who is not familiar with the language itself.

(8) Great computational speed provides efficient and economical computer usage.

The disadvantages of GPSS are the following:

(1) The manner of design and the input data should be designed according to the Reference Manual written specifically for the Univac 1108 computer by the Univac Data Processing Division.

(2) The maximum number of transactions in the system are limited to 1000 and the number of parameters are limited to 8.

(3) No complicated statistical distributions can be incorporated. As a research language it does not possess sufficient flexibility to perform the types of mathematical computation that would be of interest.

In preparing for simulated experimentation with a printing job shop problem, the first step is to construct a conceptual model which represents the manufacturing system in mathematical and logical terms. This model will be simple, omitting many details of the actual situation. Since the scheduling-sequencing printing job shop problem is concerned with detailed operations within a plant, the appropriate model will be quite complex.

The second step is to program using GPSS II as a computer language to simulate the operation of the printing section by operating the model.

CHAPTER IV

CHARACTERISTICS AND CONSTRAINTS

Importance of the Problem

There exists a relatively large number of jobs at any time, far in excess of normal loading requirements. Some of these jobs may be nearing completion, and others may not yet have started their first operation. Some of the jobs may be quite simple and require only two or three operations for their completion, while others may call for many operations requiring considerable time on the shop floor. Some jobs may be proceeding according to schedule, while others may be held up waiting for paper, ink, or master plates. The overall picture is complex and always changing. Effective printing shop floor control requires:

(1) Control over the progress of work through the shop to ensure that due dates are met.

(2) The operation of shop facilities in such a way that machines and men are efficiently used without excessive idle time or overtime and without unnecessary disruption of the workflow.

Each job is unique, a specified quantity made to special customer order which may never be repeated. Production is in lots of a specified quantity.

The degree of skill needed to operate the equipments varies a great deal. In general the more complex and versatile the machine, the greater the skill required to set up and operate it. There are many possible combinations of men and machines. The composition of men and machines that make up the productive capacity of the shop varies considerably, depending on the volume, variety, and nature of the final products.

Complexity of the Problem

Once manufacturing orders are received they are scheduled, and must be directed through the shop so as to maintain an optimum balance among three objectives

(1) On schedule performance

(2) Fullest utilization of resources

(3) Minimization of inprocess inventories

Maintaining proper balance among these objectives constitutes a particularly difficult problem, for each objective tends to conflict with each others. For example, if on schedule performance were the only objective, it could easily be achieved by having unlimited machines and manpower. Material queues would be nonexistent. There would be no waiting. The time required to complete an order would be no greater than that needed for actual processing. All orders would be completed on schedule, and inprocess inventory would be minimized. From a practical standpoint, though, the cost of excessive capacity would be prohibitive.

If on the other hand, the fullest utilization of resources were the only objective, large material queues could be established. This would completely eliminate the possibility of idle time. It would also provide an opportunity to consolidate orders for like parts into a single run avoiding repetitive set-ups that are frequently difficult and expensive to perform. Even when complete consolidation is not possible, orders could be selected to partially utilize a previous set up and make some contribution towards increased efficiency and low manufacturing cost. Selecting orders on this basis exclusively, however, would more than conflict with delivery requirements. In addition, even if there were insufficient floor space (which is generally not the case), the investment in work-in-process inventory required to maintain large material queues would be far too costly.

Although the limited availability of men, machine, material, and time is taken into account during the scheduling of orders, no plan can be devised to protect itself from change. Machine breakdowns, rush orders, excessive scrap, failure of a worker to meet expected performance are a few likely events that may disrupt the schedule. The shop control system must be capable of interpreting the production schedules in light of constantly changing conditions.

A review of the literature indicates that very little work has been done in developing a method of handling the job shop capacity requirements problem. There has been some reference to this problem in context with larger problems of job shop control; however, there does not appear to be any appreciable amount of work designed to specifically handle this problem. Since capacity level decisions are constantly being made in actual practise, it is of interest to briefly examine how this problem is handled in Delta's printing section.

Interviews with the job shop manager indicated that past experience and intuition play a primary role in determining capacity levels at machine centers in most operating situations. The manager is familiar with the operating characteristics of the printing job shop and has an "intuitive feel" for the manner in which the orders will progress through the machine centers. He uses these "hunches" in conjunction with rough estimates and past experience to predict future work loads and then matches capacity to these predictions. Capacity levels set in this manner are many times incorrect and cause a situation requiring constant readjustment on a short notice.

CHAPTER V

REAL WORLD SYSTEM

For the purposes of this research Delta's printing requirements are defined as any and all printed matter utilized by Delta and satisfying the following conditions:

(1) Required for the efficient operation of and communication within and without Delta,

(2) Required to be manufactured according to specifications supplied by Delta personnel,

(3) Required an expenditure of capital, manpower, or equipment.

The printed matter defined above is supplied by the sources depicted in Figure 4. Since each of these sources operates independently without centralized control and since each contributes to the printing need in a different manner, a meaningful comparison of these sources is difficult to achieve. Therefore each of the source supply systems has been analyzed separately.

Printing and Mailing Section

The Printing Section is the major source of printed matter within Delta, and hence forms the major part of study in this thesis. As a source of printed material, the Printing Section is responsible for:

(a) Printing all company materials that meet the established criteria for production in the Delta print shop.

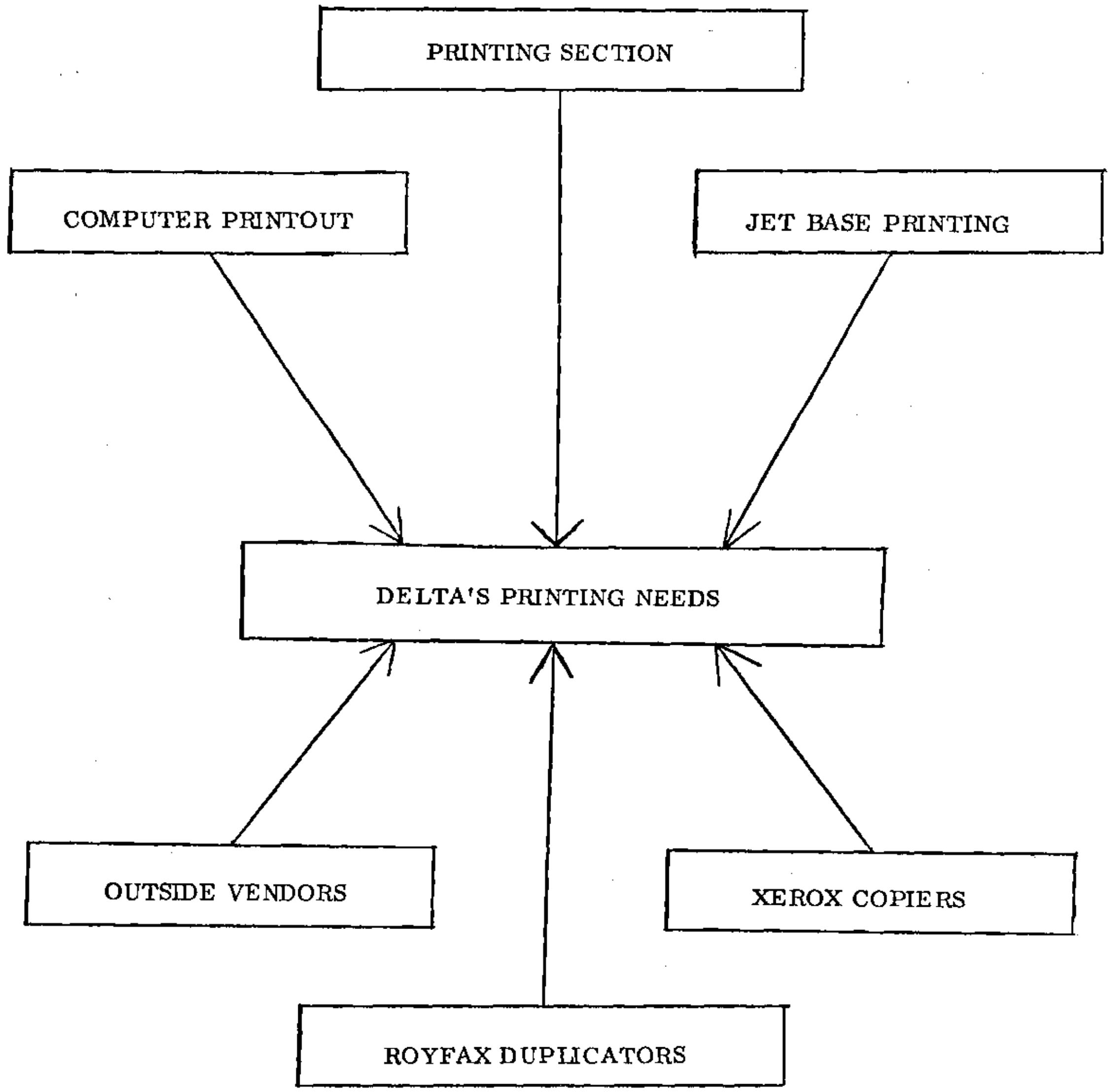


Figure 4. Source of Supply for Delta's Printing Requirements.

(b) Providing copying services to all requesting departments.

In addition, the section provides manual distribution, addressing and mailing, and mail delivery services. However, these functions are independent of printing and reproduction and will not be considered in this thesis.

<u>Organizational Chart</u>

Figure 5 shows the organizational chart of the Printing and Mailing Section. The chart illustrates the chain of command for the Printing Section and the personnel within various printing operat ions. The job title within each printing operation are determined by the experience and ability displayed by the individual and not by virtue of the particular job.

Experience Level: The Printing and Mailing Section's experience level is presented as an average figure for each job category.

Manager	20 years
Assistant Manager	11 years
Senior Printing Press Operator	7 years
Printing Press Operator	4.3 years
Junior Printing Press Operator	1.3 years
Senior Printing Clerk	12.2 years
Printing Clerk	4.3 years
Junior Printing Clerk	11.8 years
Copy Machine Operator	15 years
Printing Messenger	17 years

The Printing Section utilizes established operating principles and work procedures, together with certain equipment, as discussed below to fulfill these responsibilities as a source of printed or reproduced material.

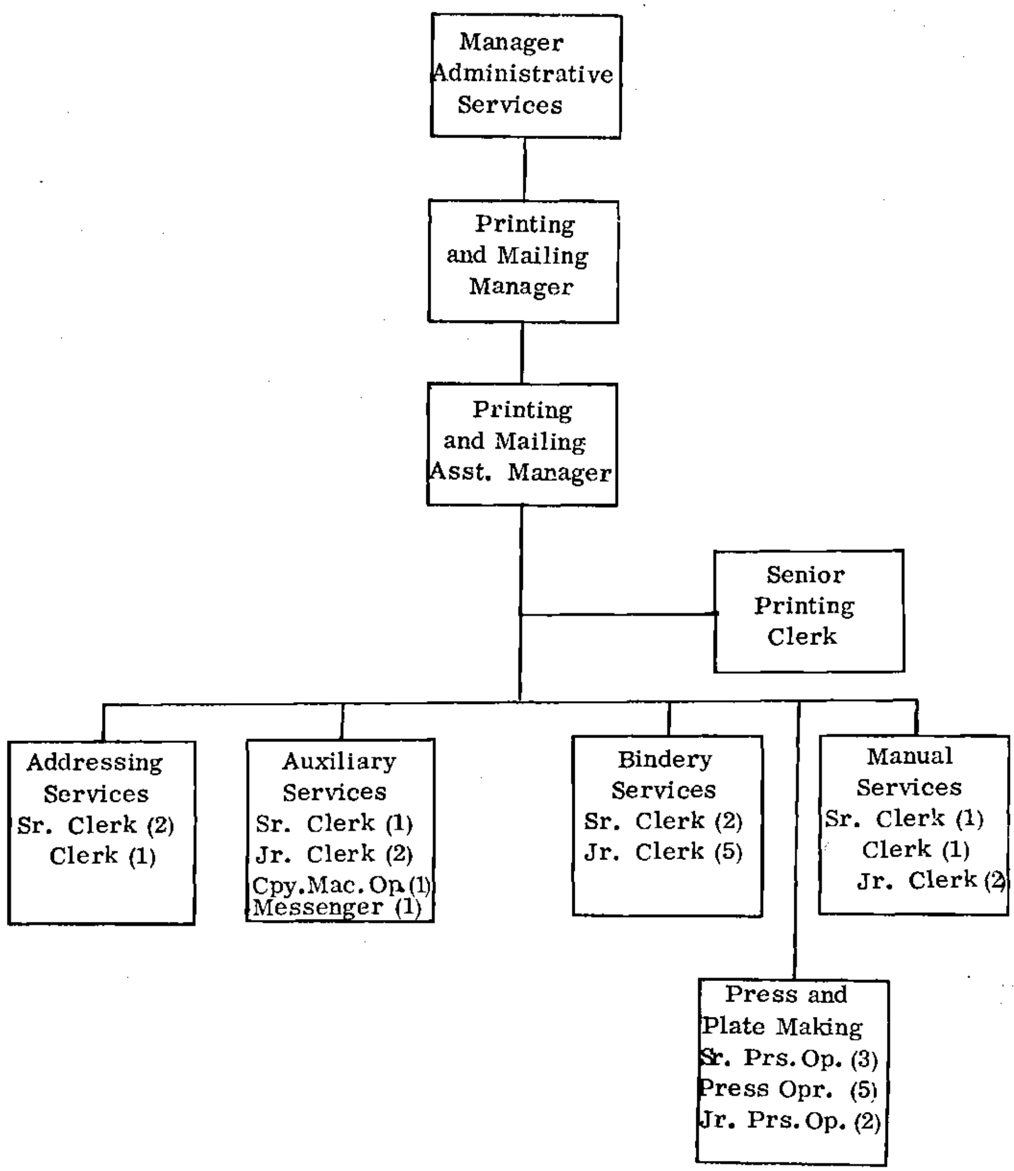


Figure 5. Delta's Printing Section's Organizational Chart.

Operating Principles

Job Acceptance Criteria: The Printing Section will accept all printing or reproduction requests unless one of the following conditions exist:

(1) Physical Dimensions: The master document is larger than 14.4 x 20.5 in. or the copy size is larger than 14 x 20 in. (cannot be produced with present equipment).

(2) Color Quality: The finished product requires a greater surface area of ink application, a more consistent ink composition, or closer registration than the present equipment can produce.

(3) Ink Surface Area and Consistency: The number of ink rollers on a press determines the press ink consistency and surface application capability. With the exception of one press (Press #5 has three ink rollers), present presses have two ink rollers. At least three ink rollers are required to transfer a large surface area of ink with the proper consistency normally required in color process work.

(4) Registration: Color process work requires a special technique of printing force impressions (one impression for each of four colors--red, blue, yellow and black). The four impressions must be consistently placed in perfect image alignment (close registration) to avoid a fuzzy appearance caused by imperfect registration.

It is possible to print close registration color work on the presses in the Printing Section, even though the presses are not designed to do color process printing. Some jobs can be printed at a lower cost to Delta by the utilization of commercial printing companies which have presses specifically designed to do color process printing.

(5) Finished Document Format: The finished product requires specialized press or finishing equipment (carbon snap out, continuous run form, etc.).

(6) Time: The Printing Section does not have the press or finishing capacity to complete a job by its due date, a later date cannot be accepted, and the job does not have priority to displace any jobs currently scheduled or on production.

(7) Job Scheduling Criteria: The Senior Press Operator (the Assistant Manager--Printing and Mailing on an exception basis) schedules all jobs in the press and finishing areas. Jobs are scheduled so as to be finished before the due date. When it is not possible to complete all jobs by the due date, the jobs with lowest priority are displaced.

(8) Operating Procedures: The Printing Section's work procedures are keyed on two variables: job specifications and the date it must be finished. The Printing Department Job Order Request (PJO), Form 0412-20022, provides the needed information on each job. The PJO is usually originated by the requester, except in the case of stock items. The Purchase Order Requisition (POR) is used by the requester to order stock items. The Senior Printing Clerk originates the PJO when a POR is received.

Specification data includes

Identification: Job description or Title, originating department and division, authorizing signature.

Printing Specifications: Number of copies, paper type, size, color, ink color(s), assembly and finishing requirements (collating, punching, stapling, stitching, folding, cutting, padding, packaging)

The operating procedures initiated by either a PJO or POR are as follows:

(a) Job Evaluation: The Senior Printing Clerk received all job requests and determines if they are acceptable for Printing Section production based on the acceptance criteria described earlier. If a particular job is questionable, the Assistant Manager, Printing and Mailing, analyzes and makes the final decision on an exception basis.

(b) Job Scheduling and Completion: Jobs that can be printed in the Delta Shop, receive a job number (sequential by date and month received) which the Senior Printing Clerk enters on a daily log sheet. Job routing through the shop is then scheduled as follows:

(i) If the job requires printing, the order is first routed to the plate making area for production of either Xerox, Itek, or metal plates. If a metal plate is already on file, it is retrieved and attached to the order. Direct impression jobs (printing plates completed by the requester) go directly to the press section. If the job does not require printing, the order is routed to the appropriate accessory equipment section (binding, punching, etc.) in the logical sequence required.

(ii) The PJO and printing plate(s) are routed to the press section (a specific press number, if so specified by the Senior Printing Clerk). The Senior Printing Press Operator merges these with those already on hand for a specific press location, so orders will be worked in due-date sequence.

(iii) Upon completion of the printing, the PJO and printed material is routed to the accessory processing areas in the logical order required.

(iv) When all required production operations are completed, the finished materials are routed to the appropriate area for distribution, delivery, or pick up. If addressing is required, the materials are delivered to the addressing section; if the finished product is a stock item, it is placed in material transporters provided for transfer to Material Services.

(9) Printing Equipment: Each functional area of the Printing and Mailing Section has equipment assigned for performing the respective parts of the printing operations. The production characteristics of the printing presses are listed in Figure 6.

	MACHINE IDENTIFICATION		PRODUCTION SPECIFICATIONS			SPECIFIC USAGE
Press No.	Manufacturer/Model	Type	Max. Sheets Size-Ins. Size	Max. Image Size-Ins.	Rated Output Imp/Hr.	
1	A.B. Dick 350	Offset dupl. standard	11 x 17	9.5 x 13	9000	Short to medium run, high quantity
2	A. B Dick 350	Offset dupl semi auto.	11 x 17	9.5 x 13	9000	Short run, low quantity jobs
3	A.B. Dick 357	Offset dupl. automatic	11 x 17	9.5 x 13	9000	Short run, low quantity jobs
5	Royal Zenith	Offset dupl. standard	14.4 x 20.5	14 x 20	5000	High run, high quality
6	A. & M. 1275	Standard	11 x 17	9.5 x 13	6000	Two-side printing
7	A. & M. 1275W	Automatic	11 x 17	10.5 x 16.5	7500	Two-side printing
8	A.B. Dick 360	Offset dupl.	11 x 17	10.5 x 16.5	9000	Medium run, high quality

Figure 6. Operating Characteristics of each Printing Section Press.

CHAPTER VI

MODEL FORMULATION

Introduction

The model formulation consisted of two related steps. The first step consisted of translating the real world system into a representative model and then testing the model to determine how closely it represents that system. The simulation of the system in a language such as ALGOL or FORTRAN would be very tedious. Hence a special purpose language called GPSS II was chosen.

Construction and Validation of the Model

The operational system outlined in Chapter V was transformed into a computer model by constructing a logic flow diagram and then translating it into a GPSS II computer program.

Model Construction

This model attempts to simulate a real world printing job shop section. Each source of printed matter that took place from July 1968 to June 1969 was considered in defining the present system of supplying printed matter. All the required data were then collected and sorted out into meaningful distribution groups. Once the required data were collected and sorted out, the construction of the flow diagram remained a matter of matching routing procedures, decision factors and components of the subject system with the appropriate GPSS II logic. Each block of the diagram includes a brief description of the block's function in the model and a unique block number.

While the symbology of GPSS II is easy to follow, an examination of its role in the model and the decision logic employed requires some explanation.

In this program the priority blocks will be discussed separately. The first block of the program entitled ORIGINATE, creates a predetermined number of jobs to operate within the system. In order that the system comes closer to reality the simulation run is first carried out for 1000 time units and is then started for the final run. Hence the model was first allowed to reach steady-state conditions before the compilation of statistics.

Functions

Function 1: This refers to the number of days after which a certain job becomes due. It is a set of fourteen continuous pairs of numbers and whose argument is a random number in the interval from 0 to 1.

Function 2: This function gives us the number of impressions to be made per job. This value is assigned to parameter 2.

Function 4: This gives one the size of the master plate. If the size is large, medium or small it is referred to as 1, 2 and 3 respectively. The value of this function is assigned to parameter 3.

Function 5: This function refers to the quality of the jobs. They are classified as high, medium, and low and are referred by parameter 4 as 1, 2 or 3 respectively.

Function 6: This function gives the number of impressions to be printed out per master plate. This function refers to the lowest quality of printing and hence the number of impressions per master plate are relatively large.

Function 7: This refers to the number of impressions to be made for medium quality printing. Here the number of impressions per master plate is much smaller than those for low quality printing.

Function 8: This refers to the number of impressions to be made for the highest quality of printing. Here the number of impressions per master plate is extremely small to gain a fine reproduction.

Function 9: This refers to the time taken in preparing a high quality master plate. The time taken for making such a plate varies from 30 mins. to 120 mins.

Functions 10 and 11: These two functions refer to the set up times taken by the printing machines.

Functions 12 and 13: These two functions refer to the set up times taken by the collating machines.

All these functions were plotted from data extracted from the records of an actual printing shop company. All the printing machines are regularly serviced by the makers of the machines and so the probability of breakdown is neglected in this model. Every machine is serviced once a month and the servicing time is only four hours. Hence the assumption that no breakdowns take place is thus justified within the scope of this model.

Variables

Variable 1: This converts the value of the due date of a job from days to minutes. This is necessary because all the set up times and processing times are in minutes.

Variable 2: This gives the number of master plates to be made. It is found by dividing the total number of impressions by the number of impressions per master plate.

Variable 3, 5, 6, 7, 8 and 9: All these variables give the total processing time which is the sum of the set up time and the actual printing time taken.

Variable 4: This gives the due date priority value. It is equal to a large number (900000) minus the clock time and the due date value in minutes.

Variable 10: This gives the total processing time taken on the perforating and folding machine.

Variable 11, 12 and 13: These variables give the total processing time of the collating machines. The total processing time is equal to the set up time plus the actual collation time.

When a job arrives at the printing shop it is first reviewed for quality, color, size and due date. Now 2.5 percentage of all the jobs that are received cannot be accomplished within the printing shop for any one of the following reasons:

(1) The master document is larger than 14 x 20 inches. The present equipment cannot handle larger sizes.

(2) Sometimes jobs require specialized press or finishing equipment (carbon snap out, continuous run form, etc.). These jobs cannot be done because of lack of sophisticated machinery.

(3) Rush orders that cannot be accomplished within the press are given to outside parties.

(4) Some jobs can be printed outside at a lower cost because of the specific design of these commercial printing presses.

Once the job has been decided to be done within the printing shop then the job is assigned a date for processing, the number of copies per master plate and the number of master plates are then found by taking into consideration the quality and quantity of the final reproduction. The size of the master plate, ink color and quality of printing are also assigned. The jobs are then given a due date priority and are then made to wait in a queue.

When the jobs enter the printing shop they are routed according to their quality of printing, size of master plate, and color combination. This is done by COMPARE blocks, which compares the parameter values of 3 and 4. If the value of parameter 3 equals one then only metal master plates can be made and hence the job is routed accordingly for making a metal master plate. The value of parameter 4 gives the quality of printing. If it is equal to one then the printing is of a high quality and so a metal master plate will have to be prepared. If the value of the parameter 4 is 2 or 3 then the quality of printing is medium and low for which Itek plate and Xerox master plate are respectively made.

For master plates that are made out of metal there are a number of repetitive orders. Thus forty percent of the metal plates used in a year are already in store, so these are retrieved and the impressions made directly. The remaining sixty percent of the metal plates made in a year are all new ones. Function 9 gives the total processing time involved for preparing a metal master plate. Now if the size of the master plate is no greater than 10.5" x 16.5" then the jobs can be processed only on the Royal Zenith because of its large sized master plate processing capability. Hence large sized jobs are first routed to this machine. If the master plate is less than 10.5" x 16.5" then these jobs are made to wait in a queue until either the Royal Zenith or the A. B. Dick 360 become available. Total processing times are assigned by variables 3 and 6 to parameter 7. These jobs are then processed which is done by the HOLD block for the time value in parameter 7. Once the printing process of these jobs is completed then they are sent either to the folding machine or collating machine for further processing.

The medium quality jobs master plate is normally made on an Itek plate maker machine while the low quality master plates are made on a Xerox machine. All the medium and low quality jobs first stand in a queue in front of the machines used for processing them and then go to any one of the machines which are available for use. This is done with the help of GATE blocks which permit transactions to go to the HOLD block (facility) only when it is free. Now the A and M 1275 and the A and M 1275W machines are both two side printing (i.e. they print on both sides of the paper simultaneously) whereas all the three A. B. Dick machines print on only one surface. Past historical data show that about 65 percent of the jobs being printed on the A. B. Dick machines are rerun for printing on the backside. This looping is done by means of an ASSIGN and COMPARE block. Initially parameter 3 is assigned the value 0. The value of the parameter 3 is checked by a COMPARE block for its value. If it is equal to 1 then it is not sent back but proceeds to the next machine for further processing. If the value of parameter 3 is equal to 0 then it does not enter the COMPARE block. The jobs are then split by the next block which is an ASSIGN block into two parts. Forty-five percent go on to the next machines while the remaining sixty-five percent are sent back to the HOLD block for reprocessing (printing). The ASSIGN block also changes the value of parameter 3 to 1. Hence when the job leaves the HOLD block and enters the COMPARE block, the condition that the parameter 3 equals 1 is satisfied and hence these jobs are routed to the next machines for further processing.

After printing is over the value of the parameter 6 which contains the number of master plates is checked whether it is equal to 1. If it is equal to 1 then no further processing is required and hence the job goes to the dispatch section as a finished job ready for dispatch. If the value of parameter 6 is greater than 1 the number of master plates is greater than one and so these jobs go for collation and stapling at the next machines.

Normally collation is done on the two small collating machines which have 10 bins each. If the number of pages to be collated is greater than 10 then multiple runs are done on these collating machines or the larger number of bins collating machines are used for collating larger number of pages. In the model multiple runs are accomplished by means of assigning a value to parameter 11. If, for example, two runs are required, then a 2 is assigned to parameter 11 and then this value is reduced by one as soon as it enters a LOOP block. After collating the next operations are stapling, stitching and folding. The finishing operation includes cutting and padding. No data was available on these operations which are straightforward and not complex, hence these operations were not included in the model.

Priority Blocks

Whenever a job arrives at the queue block; (first block of the priority blocks) it first checks whether the logic switch is reset to 1. If the switch is not reset, then the job remains in the queue. If it is reset to 1, then it first tests whether the storage 100 is full. If it is not full, then the job goes to the storage. If the storage is full, then the value of parameter 8 is compared whether it is less than or equal to X1. If this condition is fulfilled, then the job goes to QUEUE 3 where it waits until the logic switch is set to 1. If the value of parameter 8 is greater than X1 then the job goes to the SAVEX block and the new priority will be registered in the SAVEX block and will then go and stand in QUEUE 2. The value of the parameter 8 is then tested whether it is less than X1. If it is less than X1 then it is sent to QUEUE 3. If P1 L X1 condition is not met then it goes to the storage 100 and then it goes out and puts logic switch to 1.

Validation

The primary objective of this research is the construction of a basic model to be later used in providing information regarding future load and utilization for each machine in the printing shop. The secondary objective is the validation of the model. To this end Delta's printing shop with standard printing shop machines was modeled. The printing methods simulated are similar

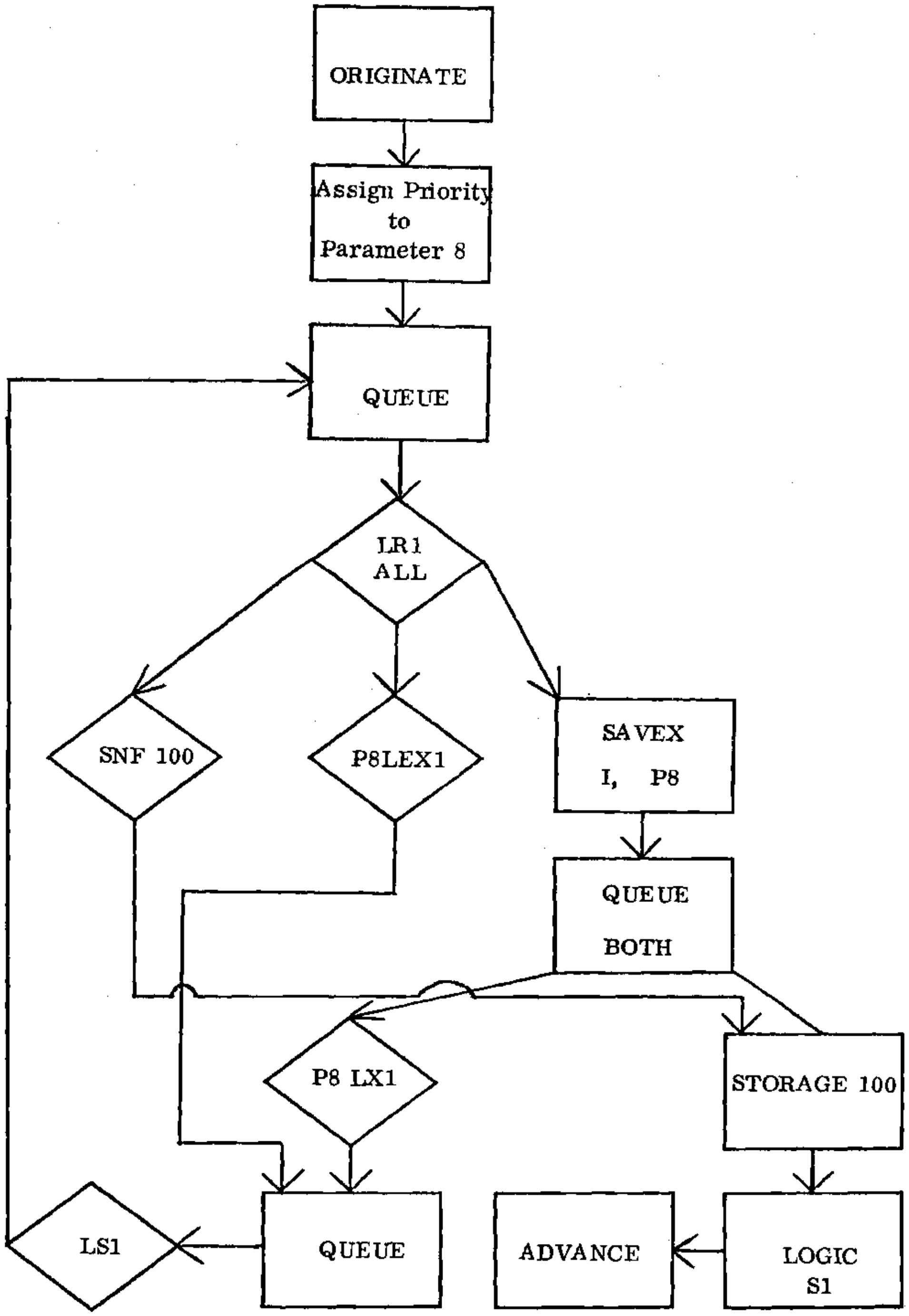


Figure 7. Due Date Priority.

to those commonly employed by any standard printing shop. The basic model should accurately portray the real world if it is to serve as a realistic point of departure for conceptual innovations.

Steady State Considerations

It appears in order at this point to take a look at and make some statements about steady state in this model. It will be assumed throughout that necessary and sufficient conditions for the existence of steady state solutions are satisfied by the system parameters. A search of the literature survey shows that there is nothing known about necessary and sufficient conditions for convergence to statistical equilibrium in any general waiting line network system. For the special case where the system arrival process is Poisson and the service at each service center is exponential, the necessary and sufficient conditions for the existence of statistical equilibrium are known to be

$$\rho_i = \lambda_i/\mu_i < 1$$

where λ_i = mean arrival rate and

μ_i = mean service rate

Since the special case is not applicable to the model constructed, an approach was necessary to check when the model was in steady state, if, in fact, it would achieve steady state. This was accomplished by running the model several increments in the number of jobs completed and printing a system statistics at the end of each one of these periods. When the statistics no longer demonstrated a trend,

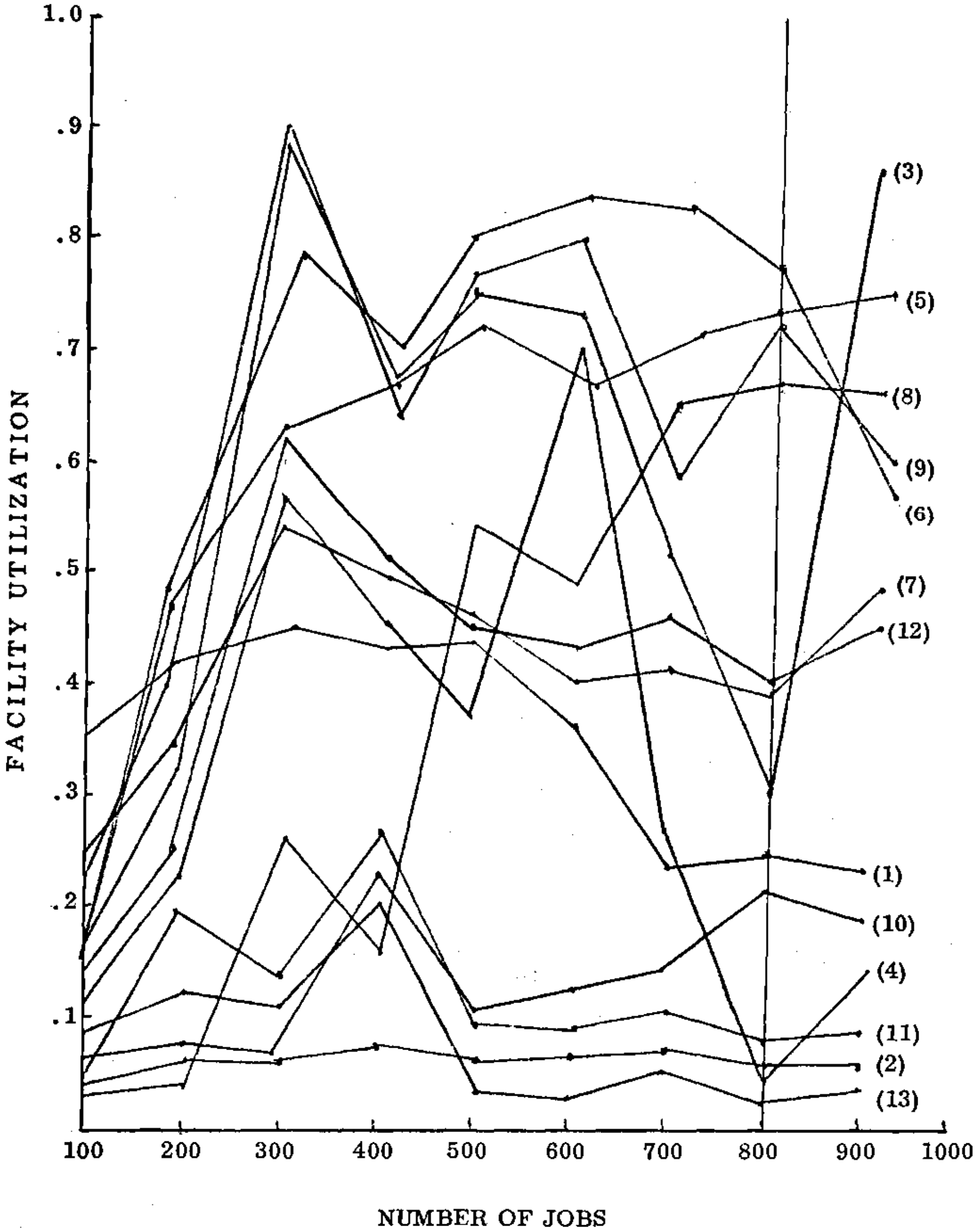


Figure 8. Steady State Analysis.

it was concluded that the model had achieved a steady state condition.

The model was first run for 100 jobs. At the end of this period the statistics pertaining to facility utilization were printed and cleared. An additional 100 jobs were run and again the statistics were printed and cleared. This procedure was repeated through 900 jobs. Thus, the statistics were printed for every 100 jobs for 100 through 900 inclusive.

The facility utilization was graphed for each facility at the end of each of these time periods. It appears, except for the facility 5 that the steady state exists at 800 jobs. The utilization varies after 800 jobs but exhibits no trend. That is, the changes are due to random variation and would be expected if a random sample of 100 jobs were taken even after 5000 jobs have been run.

An alternative criterion often used is when a statistic falls for the first time within two previous values, steady state has been achieved. Using this last criterion, all thirteen facilities exhibit steady state at or before 800 jobs are run. Based on this last criterion and the fact that no trend is exhibited, 800 jobs can be considered a safe starting point for the accumulation of steady state statistics.

CHAPTER VII

ANALYTICAL RESULTS

Analysis

The simulation model provides simplicity to expedite analysis and yet broaden the potential range of applications, and have sufficient detail to provide results which are relevant to some direct applications.

The results that the simulation model are required to show are:

1. Analysis of the queue distribution with different arrival rates.
2. The form of the queue distribution as a function of shop load.
3. Observation of the utilization of the different individual machine centers with varying arrival rates.
4. The planning of the future manpower planning. The type of machinery required will indicate the degree of skilled labor required.

Arrivals

Each job is described by a printing job order which specifies the machine centers required to completely process the job and the sequence which the job must follow. In the present existing system the number of jobs received per day varies from 50 to 60 jobs. Hence, the arrival rate was taken as uniformly distributed between 8 mins. to 12 mins. This arrival pattern is to the printing job shop system and not to the individual machine centers. The arrival to each machine center will depend upon the cumulative arrival from all other machine centers and the external arrival process.

Queues

The queue distribution is a function of the shop load, the mode of selection from the queue, and the type of service (or processing) distribution. In all the queues a first-come first-served basis of priority rule was employed. However, the job waiting in a queue was permitted to select whichever machine (or facility) was available for processing. In the present existing system the queues were building up to a fairly large extent and so jobs had to be given to outside vendors for processing. However, with increase in the arrival rate of the jobs the queues will still go on building and; hence, the number of jobs given to outside vendors will increase with time. This problem can only be solved by increased capacity and better utilization of the present existing facilities.

Processing

The processing (or service) distribution typically used in queueing theory literature is the negative exponential. However, other distributions can be used if applicable to the particular situation. In this simulation model the processing time was actually calculated by finding the set up time and the actual processing time. The set up time varied according to the number of master plates and the processing time depended on the number of impressions to be printed.

Transportation

Transportation time is the time spent to pick up, move from one machine to another and deposit only. The transportation times are not deterministic. They may obey a distribution form with some mean and variance. The variance may play an important role in the distribution because it depends on a number of factors, such as, position of material at pick-up, interference encountered in moving the material, interference in moving along the aisles, length of the route, interference at the terminal point, and the degree of precision required in location at the terminal point are probably most important. For a given route, one or all of the above may be encountered once or several times. The more often interference is encountered, the longer will be the transportation time and vice versa. In this simulation model transportation time was taken as negligible because it was insignificant compared to the processing time.

The management of the printing shop must inevitably be concerned with the problem of whether the present volume of the incoming jobs will eventually lead to an infinitely large queue size. The simulation model has some interesting implications for the solution to this problem, because management does not have to be concerned with the technological ordering of the jobs. That is, the criteria for stability are the same for a flow shop where all jobs follow a set path through the shop, as they are for a randomly routed shop, or any combination of these two extremes. The only thing of importance is the aggregate demand for processing at the machines. This simulation model provides a basis for long term planning of the production facilities such that the incoming rates and the technology of the jobs arriving at the shop match the capability of the machines.

In the first simulation run the present existing system was simulated for a time period of 120,000 time units which corresponds very nearly to a year. It was noticed that the queues build up considerably in front of the medium and low quality presses (maximum queue content = 53) and also in front of the ten and sixteen bin collating machines (maximum queue content = 27). This gave rise to a very high utilization factor which ranged from 0.9382 to 0.9987 for the presses and from 0.7542 to 0.9461 for the collating machines. The percentage of jobs that were past their due dates (late) were 11.11 percent. This clearly indicates a lack of available machine capacity to process the incoming jobs on time. The average time for the presses ranged from 20.91 to 62.73 while for the collating machines it ranged from 9.53 to 13.64 time units.

The rate of growth for the incoming jobs is about 3 percent a year. Taking this growth rate the simulation model was run for a future period of 6 years from the present. In this simulation model all the jobs that were given to outside parties were routed through the printing job shop with an additional press machine. The simulation period was once again chosen as a year. The results of this run was also very similar to that of the previous run; however, the size of the queue before the medium and low quality presses was smaller than the previous simulation run. (Maximum queue contents = 29). However, the queue before the tenth and sixteenth bin collating machine increased considerably. (Maximum queue contents = 59.) This was due to the reason that all collating jobs larger than 10 but smaller than 50 are done on the ten bin collating machines by carrying out a multiple run. This multiple run can be avoided by making use of the fifty bin collating machine for jobs which need greater than 16 bins for collating. The facility utilization ranged from 0.8243 to 0.9791 for the presses and from 0.8541 to 0.9826 for collating machines.

In the third simulation run an additional press was added and the system was once again simulated for a year. Here the fifty bin collating machine was used for all jobs requiring more than 16 bins for collation. It was observed that the maximum queue contents in all cases was 1 and the facility utilization ranged from 0.5241 to 0.8141 for the presses and from 0.5031 to 0.8654 for the collating machines. This clearly is the optimum system and it will help to get all the jobs being presently done by outside parties within the printing job shop itself. Using the Printing Section's cost savings estimate; 20 percent (49,000) of the total cost ($245,000) could be saved annually if the printing section produced these jobs. An accurate cost and savings analysis was not attempted due to lack of cost figures.

This clearly is the optimum system as it will help get all the jobs being presently done by outside parties within the printing job shop itself. Furthermore, this optimum system takes the growth rate of the future into consideration as well.

Facility Number	Type of Machine	Avg. Time/ Transactions (Minutes)	Facility Utilization
1	Prepare Metal Plates	51.92	0.3551
2	Desk Clerk	10.00	0.8301
3	Royal Zenith	149.90	0.7061
4	A. B. Dick 360	32.94	0.2861
5	A. & M. 1275W	28.57	0.9987
6	A. & M. 1275	62.73	0.9888
7	A. B. Dick 350	20.91	0.9634
8	A. B. Dick 357	22.69	0.9382
9	A. B. Dick 350	13.06	0.9449
10	Thomas Rotomatic	9.53	0.9461
11	Thomas Rotomatic	13.38	0.7542
12	Thomas Rotomatic	13.64	0.8489
13	Folding M/C	50.67	0.2454

Figure 9. Present System.

Facility Number	Type of Machine	Avg. Time/ Transactions (Minutes)	Facility Utilization
1	Prepare Metal Plates	51.96	.3442
2	Desk Clerk	9.96	.8321
3	Royal Zenith	99.50	.8242
4	A. B. Dick 360	37.73	.3567
5	A. & M. 1275W	24.43	.9791
6	A. & M. 1275	13.44	.9529
7	A. B. Dick 350	20.63	.8425
8	A. B. Dick 357	21.28	.8243
9	A. B. Dick 350	16.25	.0627
10	Thomas Rotomatic	48.48	.9826
11	Thomas Rotomatic	16.89	.8541
12	Thomas Rotomatic	15.20	.9175
13	Folding M/C	49.41	.2937
14	A. & M. 1275	25.27	.9154

Figure 10. Future System with Increased

Arrival Rate and Capacity.

Facility Number	Type of Machine	Avg. Time/ Transactions (Minutes)	Facility Utilization
1	Prepare Metal Plate	49.92	.3451
2	Desk Clerk	9.98	.8378
3	Royal Zenith	99.43	.8236
4	A. B. Dick 360	39.41	.3648
5	A. & M. 1275W	25.39	.8141
6	A. & M. 1275	17.89	.7329
7	A. B. Dick 350	17.51	.5249
8	A. B. Dick 357	16.98	.5141
9	A. B. Dick 350	17.24	.0634
10	Thomas Rotomatic	43.24	.8654
11	Thomas Rotomatic	19.39	.7643
12	Thomas Rotomatic	13.29	.9024
13	Folding M/C	52.54	.5031
14	A. & M. 1275	35.29	.6834
15	A. & M. 1275	21.78	.5431

Figure 11. Future System with Increased Arrival Rate, Capacity and Efficient Utilization of Collating Machines.

CHAPTER VIII

CONCLUSIONS AND RECOMMENDATIONS

The objective of the proposed research was to develop a simulation model to study the present printing job shop section and evolve a new design so as to process all jobs within the printing section. The model selected for research was aimed at developing the understanding necessary to predict a printing shop system behavior as a function of facility utilization. The model employed in this research is restricted by the standard set of assumptions outlined in Chapter II. The only additional assumption is that infinite queues are allowed. At first, this may seem like an unreasonable assumption, but, if one considers the future existing optimum printing job shop, semifinite queues do exist. That is, jobs are not given away because of any queue blocking. It may be that additional storages or machine capacity may be necessary at a temporary location, but this storage or machine capacity can be usually provided.

The objective of the thesis was achieved by providing an approach of predicting a future optimum system for not only the growth rate but of getting the jobs that are also presently being done by outside parties within the printing shop itself. The model provides simplicity to expedite analysis and broaden the potential range of applications, and yet have sufficient detail to provide at least some results which may be relevant to some direct applications.

Several additional avenues of exploration are open:

1. This model can be extended to any system by slight changes in the model which may result in

   a. greater depth to which description and prediction are obtainable. This may be enhanced by the lack of complicating details in the model.

   b. The results obtained by modifying the model may be of direct application or provide an insight for further advances in a broad class of problems like scheduling, cost reduction, etc.

2. Conway (10) showed that a simple infinite queue with Poisson arrivals and exponential service time displaces the arrival rate in time only. Therefore, the output is exponential. Poisson arrival rate and exponential service are a necessary and sufficient condition for this result to be true. Since exponential service times were not employed in the simulation model because the service time distribution was not known; hence, it is not known what the output of any machine center is. Therefore, the arrival distribution to any individual service center would not be known. It would be a combination of the external arrival rate and the unknown arrival rate from the service centers. Hence, this would very well be an interesting area of study.

3. Investigation of the possibility of isolating jobs of a similar nature and processing these jobs on one particular machine. This will lead to shorter set up times and trial runs.

4. It would be interesting to study the extended problem in which the printing job shop has multiple inventory items. The simulation model can be extended to include this situation, because the number of impressions processed gives a direct relationship to the amount of papers and ink processed. The multiple inventory item could not be included in the simulation model due to lack of sufficient data.

APPENDICES

APPENDIX 1. GPSS II COMPUTER PROGRAM

```
LOC   NAME           X      Y      Z      SEL    NBA    NBB    MEAN   MOD    REMARKS   F

      JOB
*     DUE DATE PRIORITY
 1    FUNCTION       RN1    C14
0     0      .138    1      .259   2      .381   3      .433   4      .482   5
.631  6      .769    7      .803   8      .835   9      .852   14     .954   19
.989  29     .999    39
 2    FUNCTION       RN1    C5
0     2      .001    4      .153   6      .924   8      .999   9
 3    FUNCTION       RN1    C13
0     1      .264    5      .429   10     .555   49     .788   199    .915   499
 .973 999    .986    1999   .990   4999   .993   9999   .996   19999  .998   29999
.999  49999
 4    FUNCTION       RN1    D3
.013  1      .984    2      1.0    3
 5    FUNCTION       RN1    D3
.0807 1      .2403   2      1.0    3
 6    FUNCTION       RN1    C16
0     1      .087    9      .215   19     .393   29     .529   39     .600   49
.680  59     .734    79     .761   99     .829   149    .897   199    .948   249
.962  299    .993    349    .996   399    .999   449
 7    FUNCTION       RN1    C13
0     1      .107    9      .310   19     .481   29     .596   39     .667   49
.744  59     .857    79     .870   91     .923   129    .979   149    .987   179
.999  199
 8    FUNCTION       RN1    C13
0     1      .143    4      .313   9      .424   14     .517   19     .656   29
.725  39     .839    49     .908   69     .952   99     .981   129    .992   149
.999  199
 9    FUNCTION       RN1    C4
0     30     .80     60     .95    90     .999   120
 10   FUNCTION       RN1    C4
0     1.0    .750    2.0    .950   3.0    .999   5.0
 11   FUNCTION       RN1    C4
0     1.0    .75     2.0    .95    3.0    .99    5.0
 12   FUNCTION       RN1    C4
0     8.0    .750    12.0   .950   16.0   .999   24.0
 13   FUNCTION       RN1    C4
0     8.0    .75     10.0   .95    12.0   .99    15.0
 100  CAPACITY       1
 1    VARIABLE       K8*FN1*K60
 2    VARIABLE       P2/P5
 3    VARIABLE       P6*FN10+P2*K60/K5000
 4    VARIABLE       K900000-C1-P1
 5    VARIABLE       P6*FN11+P2*K60/K6000
 6    VARIABLE       P6*FN10+P2*K60/K9000
 7    VARIABLE       P6*FN11+P2*K60/K7500
 8    VARIABLE       P6*FN11+P2*K60/K6000
 9    VARIABLE       P6*FN11+P2*K60/K9000
 10   VARIABLE       P6*FN2+P2*K60/K33000
 11   VARIABLE       K4*FN12+K1*P2*K60/K33000
 12   VARIABLE       K1*FN13+K1*P2*K60/K5000
 13   VARIABLE       K1*FN13+K1*P2*K60/K30000
 14   VARIABLE       M1-V1
```

```
201   GENERATE        1                202
202   GATE       LS1                   203
203   BUFFER                           204
204   SAVEX      1    K0               205
205   LOGIC      R1                    202
1     ORIGINATE                        2          8      2
2     ASSIGN     1    V1               3
3     ASSIGN     2    FN3              4
4     ASSIGN     3    FN4              5
5     ASSIGN     4    FN5              6
6     ASSIGN     8    V4               7
7     QUEUE      1                     10
10    GATE       LR1           ALL     11    13
11    GATE       SNF100                17
12    COMPARE    P8   LE   X1          15
13    SAVEX      1    P8               30
30    QUEUE      2             BOTH    14    17
14    COMPARE    P8   L    X1          15
15    QUEUE      3                     16
16    GATE       LS1                   7
17    ENTER      100                   18
18    ADVANCE                          19         5
19    LEAVE      100                   20
20    LOGIC      S1                    21
21    ADVANCE                  .025    22    199
22    ADVANCE                  ALL     23    26
23    COMPARE    P3   E    K1          40
24    COMPARE    P4   E    K1          40
25    COMPARE    P4   E    K2          45
26    COMPARE    P4   E    K3          50
40    ASSIGN     5    FN8              41
41    ASSIGN     6    V2               55
45    ASSIGN     5    FN7              46
46    ASSIGN     6    V2               117
50    ASSIGN     5    FN6              51
51    ASSIGN     6    V2               117
55    QUEUE      4             .40     56    62
62    HOLD       2                     257        10
56    HOLD       1                     257        1      FN9
257   ADVANCE                  BOTH    57    58
57    COMPARE    P3   E    K1          60
58    QUEUE      5             BOTH    161   162
161   GATE       NU3                   63
162   GATE       NU4                   65
60    QUEUE      5                     63
63    ASSIGN     7    V3               64
64    HOLD       3                     130        *7
65    ASSIGN     7    V6               66
66    HOLD       4                     130        *7
117   ADVANCE                  ALL     238   241
238   GATE       NU5                   32
239   GATE       NU6                   33
240   GATE       NU7                   34
241   GATE       NU8                   35
32    ASSIGN     7    V7               119
119   HOLD       5                     130        *7
33    ASSIGN     7    V8               120
```

```
120   HOLD        6                                 130              *7
34    ASSIGN      3       K0                        320
320   QUEUE       22                                321
321   ASSIGN      7       V9                        322
322   HOLD        7                       BOTH      323     324      *7
323   COMPARE     P3      E       K1                130
324   ASSIGN      3       K1              .45       320     130
35    ASSIGN      3       K0                        330
330   QUEUE       23                                331
331   ASSIGN      7       V9                        332
332   HOLD        8                       BOTH      333     334      *7
333   COMPARE     P3      E       K1                130
334   ASSIGN      3       K1              .45       330     130
130   QUEUE       15                      BOTH      131     132
131   COMPARE     P6      LE      K1                199
132   ADVANCE                             .08       140     133
133   QUEUE       16                                234
234   GATE        NU9                               134
134   ASSIGN      8       V10                       135
135   HOLD        9                                 199              *8
140   QUEUE       17                      ALL       439     445
439   COMPARE     P6      G       K50               149
440   COMPARE     P6      G       K40               304
441   COMPARE     P6      G       K30               303
442   COMPARE     P6      G       K20               300
443   COMPARE     P6      G       K16               301
444   COMPARE     P6      G       K10               155
445   ASSIGN      11      K1                        345
300   ASSIGN      11      K3                        345
301   ASSIGN      11      K2                        345
303   ASSIGN      11      K4                        345
304   ASSIGN      11      K5                        345
345   QUEUE       20                      BOTH      244     246
244   GATE        NU10                              144
246   GATE        NU11                              146
144   ASSIGN      8       V13                       145
145   HOLD        10                                299              *8
299   LOOP        11                                145     199
146   ASSIGN      8       V12                       147
147   HOLD        11                                399              *8
399   LOOP        11                                147     199
149   ASSIGN      11      K2                        150
150   QUEUE       18                                251
251   GATE        NU12                              151
151   ASSIGN      8       V11                       152
152   HOLD        12                                499              *8
499   LOOP        11                                152     199
155   QUEUE       19                                256
256   GATE        NU13                              156
156   ASSIGN      8       V12                       157
157   HOLD        13                                199              *8
199   TABULATE    5                                 206
206   TABULATE    6                                 207
207   TERMINATE
5     TABLE       V14     0       250     100
6     TABLE       M1      0       250     100
      START               7000
```

APPENDIX 2. NAMES OF ELEMENTS

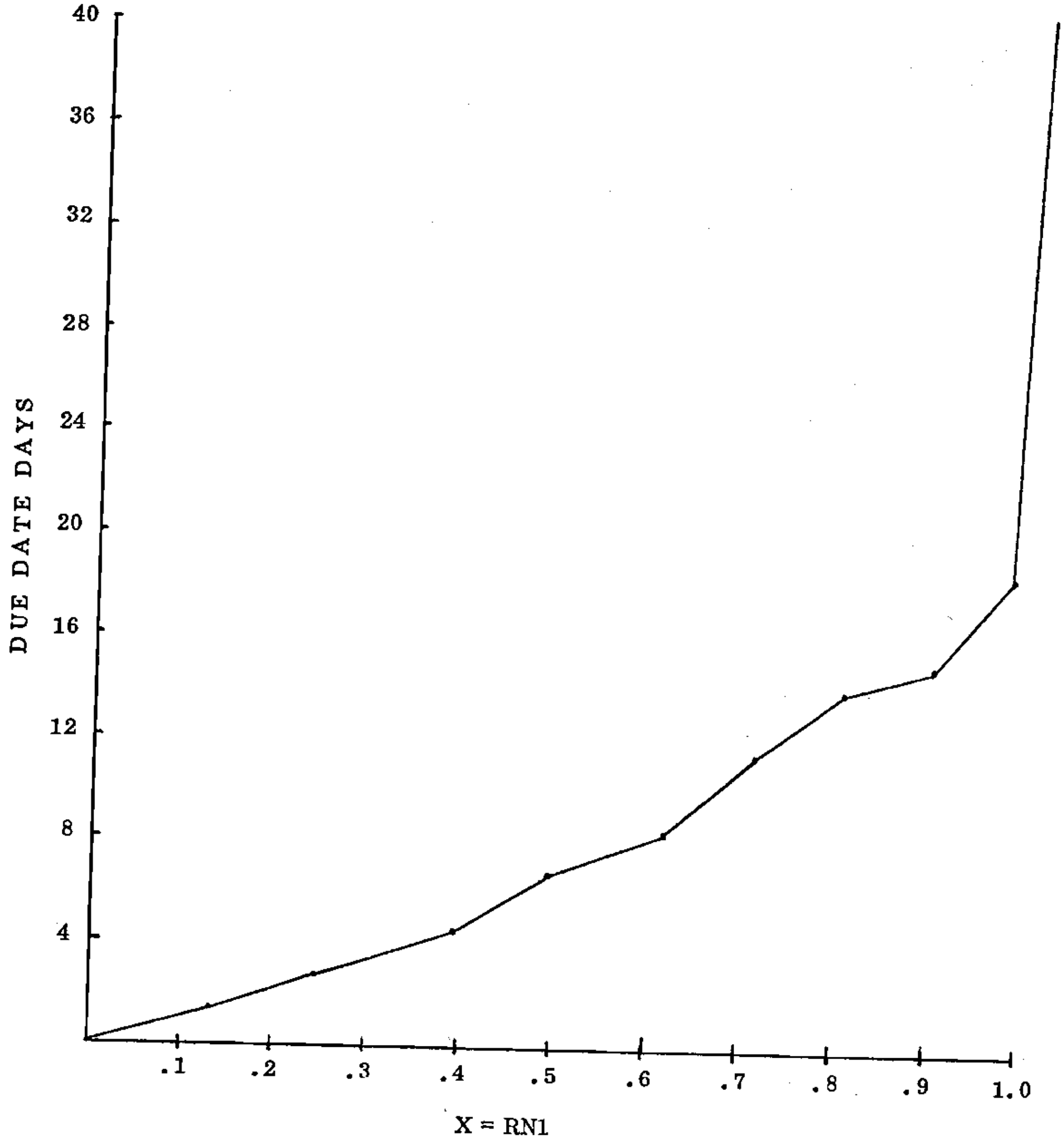
ELEMENT	CODE	BEGIN	END
1. Read and analyze Printing Job Order (PJO)	PJO	Look at or pick up pick up PJO	Put down or stop looking at PJO
2. Change ink	INK	Start to remove old ink from press	Begin another element
3. Load paper for job (includes unloading paper from previous job)	LOAD	Go get paper or unload previous paper	Begin another element
4. Attach first plate for job--direct image	DI	Pick up plate	Begin another element
5. Attach first plate for job--Xerox plate	X	Pick up plate	Begin another element
6. Attach first plate for job--metal	M	Pick up plate	Begin another element
7. Attach first plate for job--Itek	I	Pick up plate	Begin another element
8. Change plate Direct Image	DIC	Stop press to remove plate	Restart press
9. Change plate Xerox	XC	Stop press to remove plate	Restart press
10. Change plate Metal	MC	Stop press to remove plate	Restart press
11. Change plate Itek	IC	Stop press to remove plate	Restart press
12. Run samples for adjustment	SAMPLE	Start press for sample run	Begin another element
13. Run production	PROD	Start press for production run	Start press to remove product

ELEMENT	CODE	BEGIN	END
14. Finish job	FINISH	Leave area with job	Return for next PJO

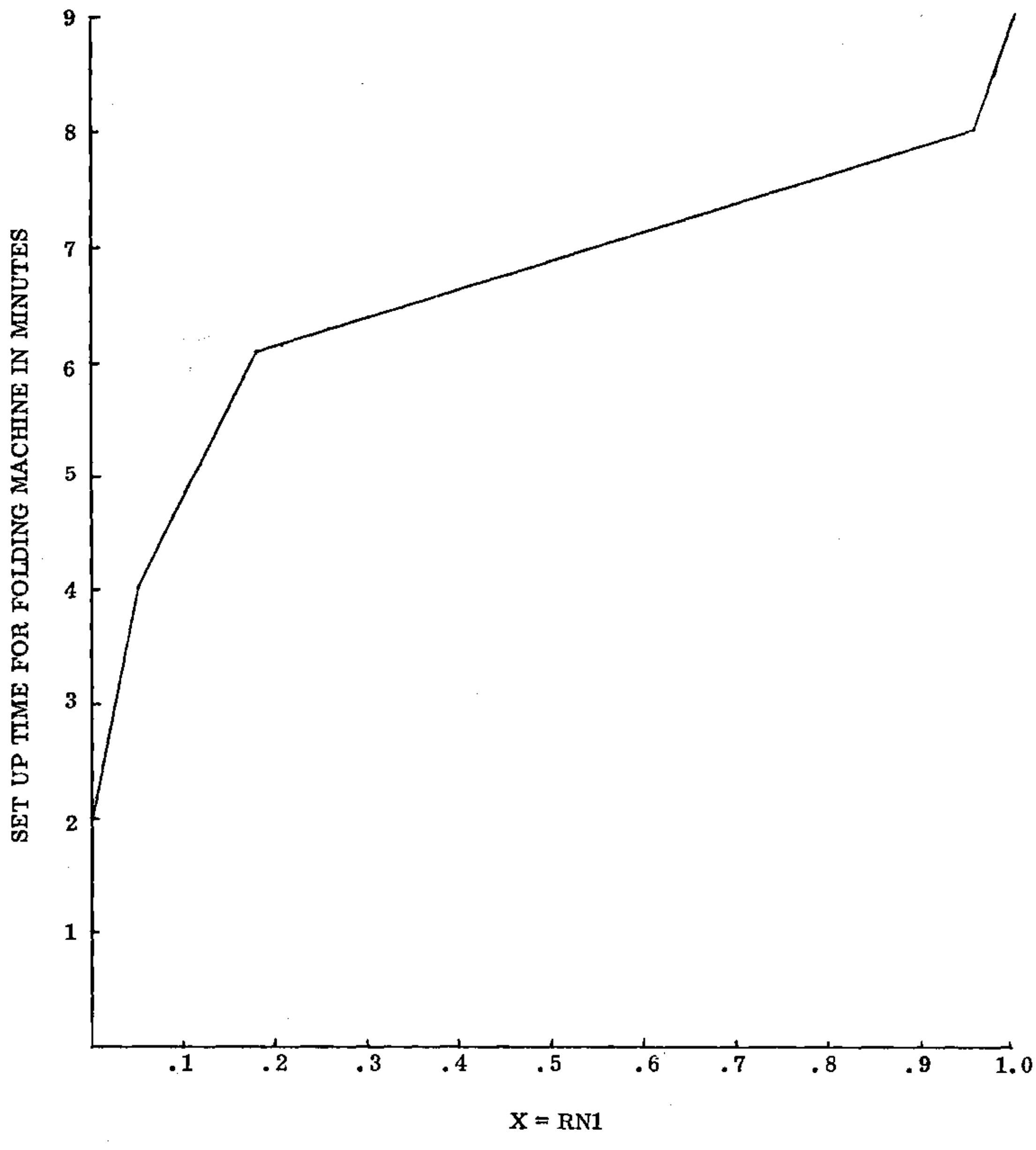
APPENDIX 3. MEAN TIMES FOR EACH ELEMENT OBSERVED IN THE PRESS

Element Code	Press 1	Press 2	Press 3	Press 5	Press 6	Press 7	Press 8
PJO	50.0sec/PJO	50.0	50.0	50.0	50.0	50.0	50.0
INK	32.0sec/PJO	32.0	32.0	35.0	70.0	70.0	N.A.
LOAD	167.2sec/PJO	167.2	167.2	150.5	143.0	143.0	167.2
DI	34.2sec/PJO	34.2	34.2	N.A.	67.5	25.0	34.2
M	137.5sec/PJO	137.5	137.5	470.0	N.A.	N.A.	75.0
I	90.5sec/PJO	90.5	90.5	N.A.	45.0	45.0	45.0
DIC	N.A.	N.A.	N.A.	N.A.	N.A.	39.2	N.A.
XC	19.2sec/plate	19.2	19.2	N.A.	43.8	24.2	N.A.
MC	137.5sec/plate	137.5	137.5	470.0	N.A.	N.A.	75.0
IC	133.8sec/plate	133.8	133.8	N.A.	41.4	41.4	41.4
SAMPLE	177.4sec/plate	177.4	103.6	2335.5	58.4	58.4	71.3
PROD	81.1sec/100	81.1	81.1	150.5	75.3	53.7	70.2
FINISH	131.4sec/PJO	131.4	131.4	131.4	131.4	131.4	131.4

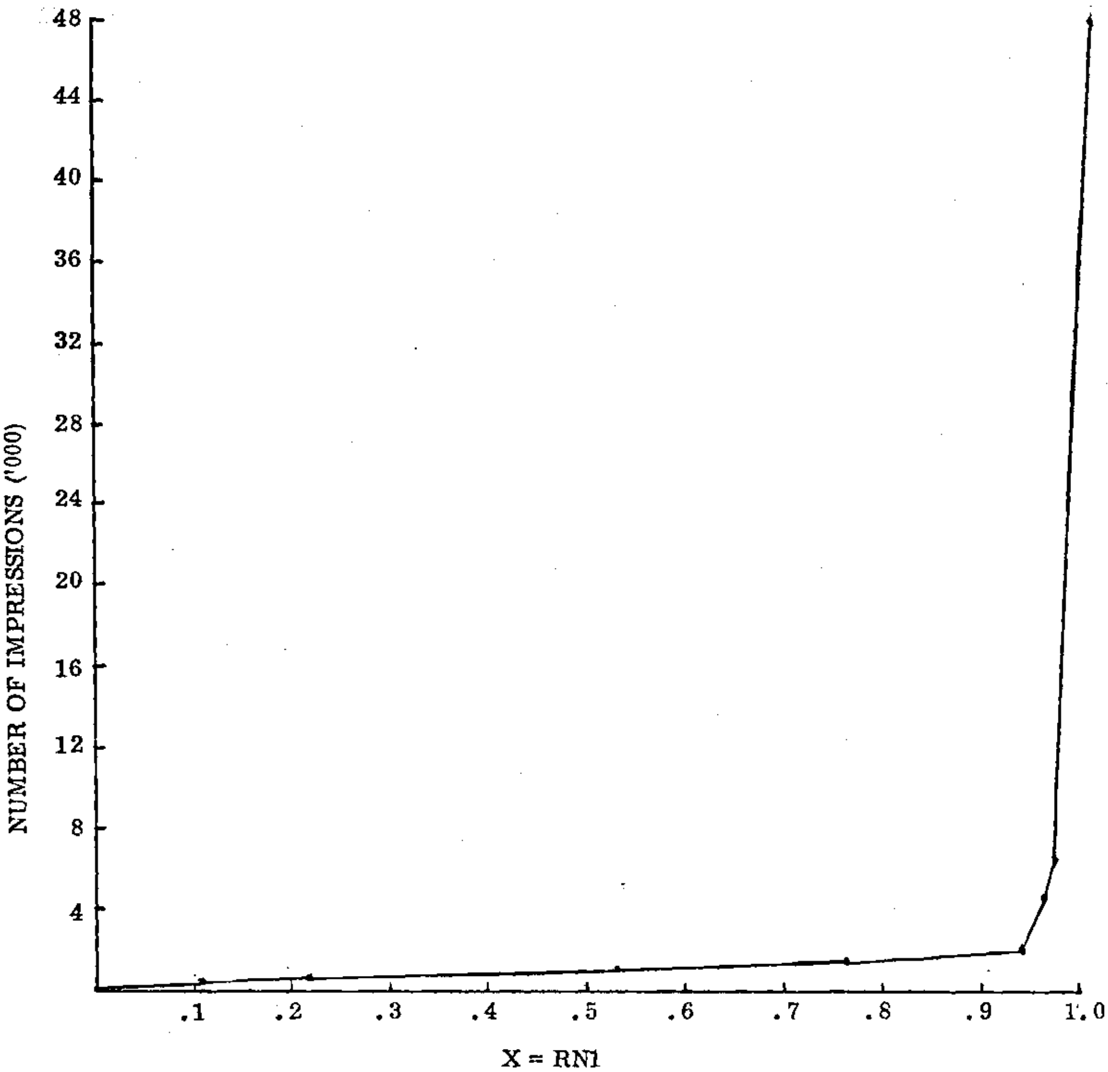
APPENDIX 4. FUNCTIONS



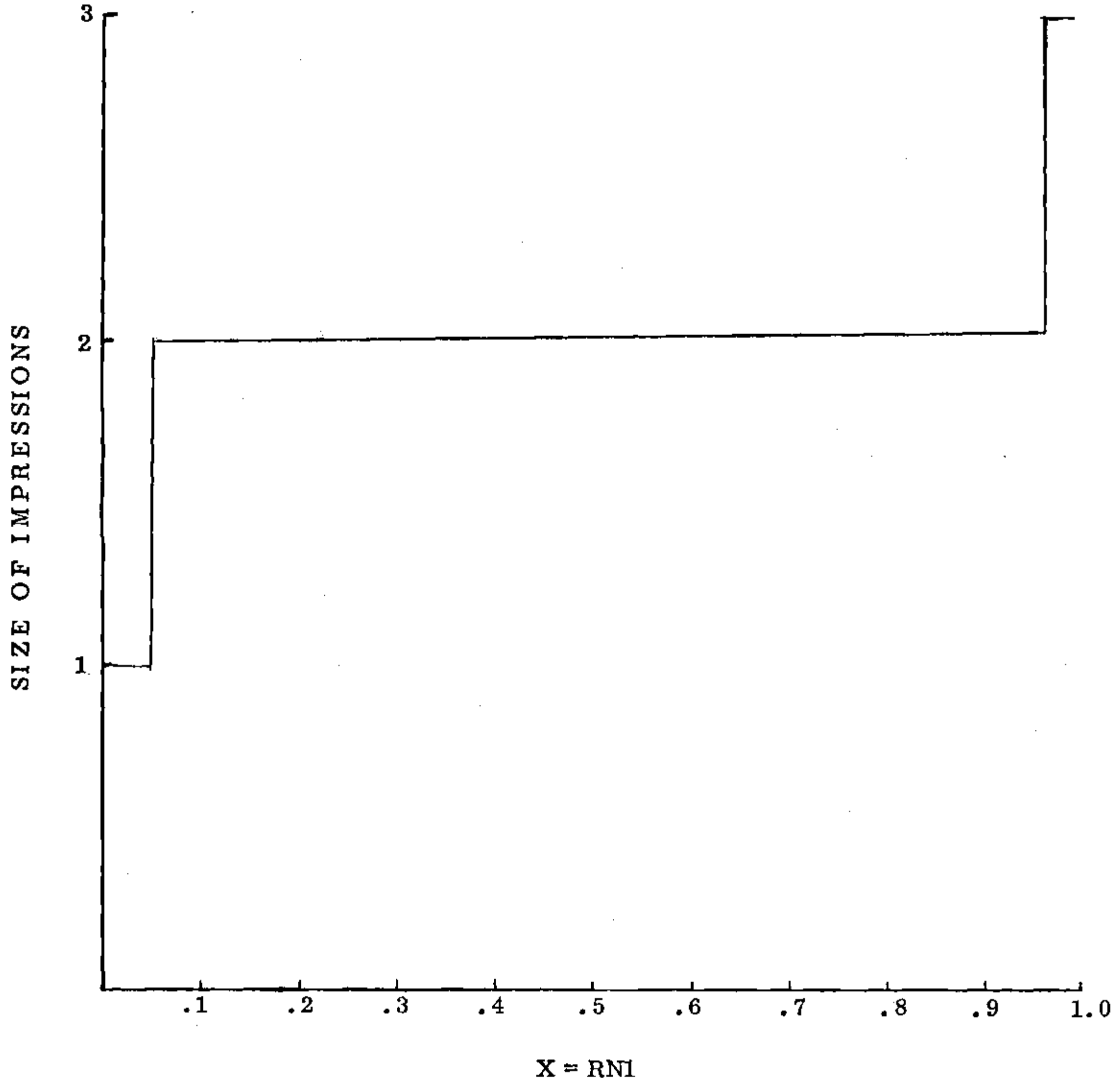
FUNCTION 1--DUE DATE IN DAYS



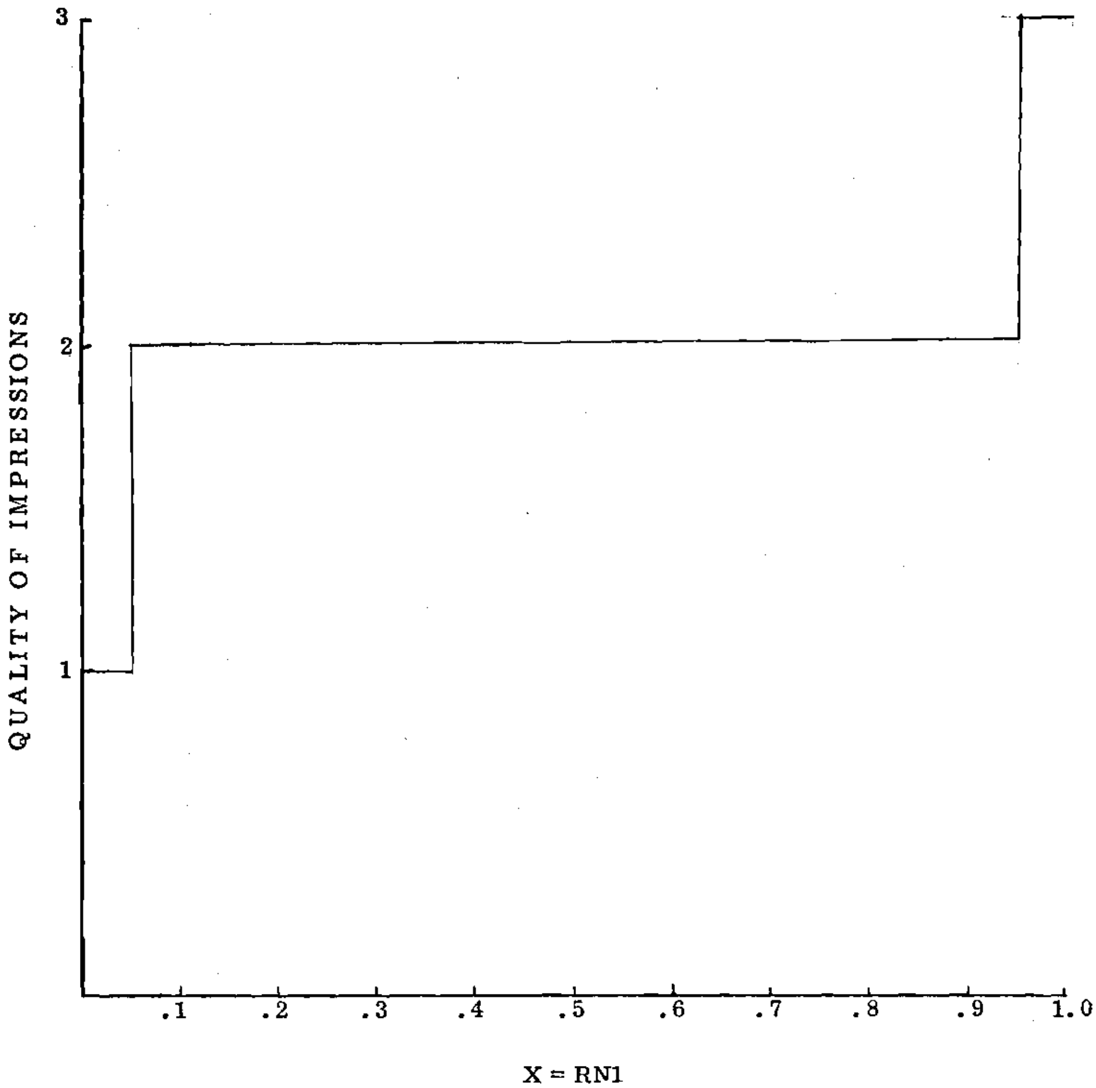
FUNCTION 2--SET UP TIME FOR FOLDING MACHINE IN MINUTES



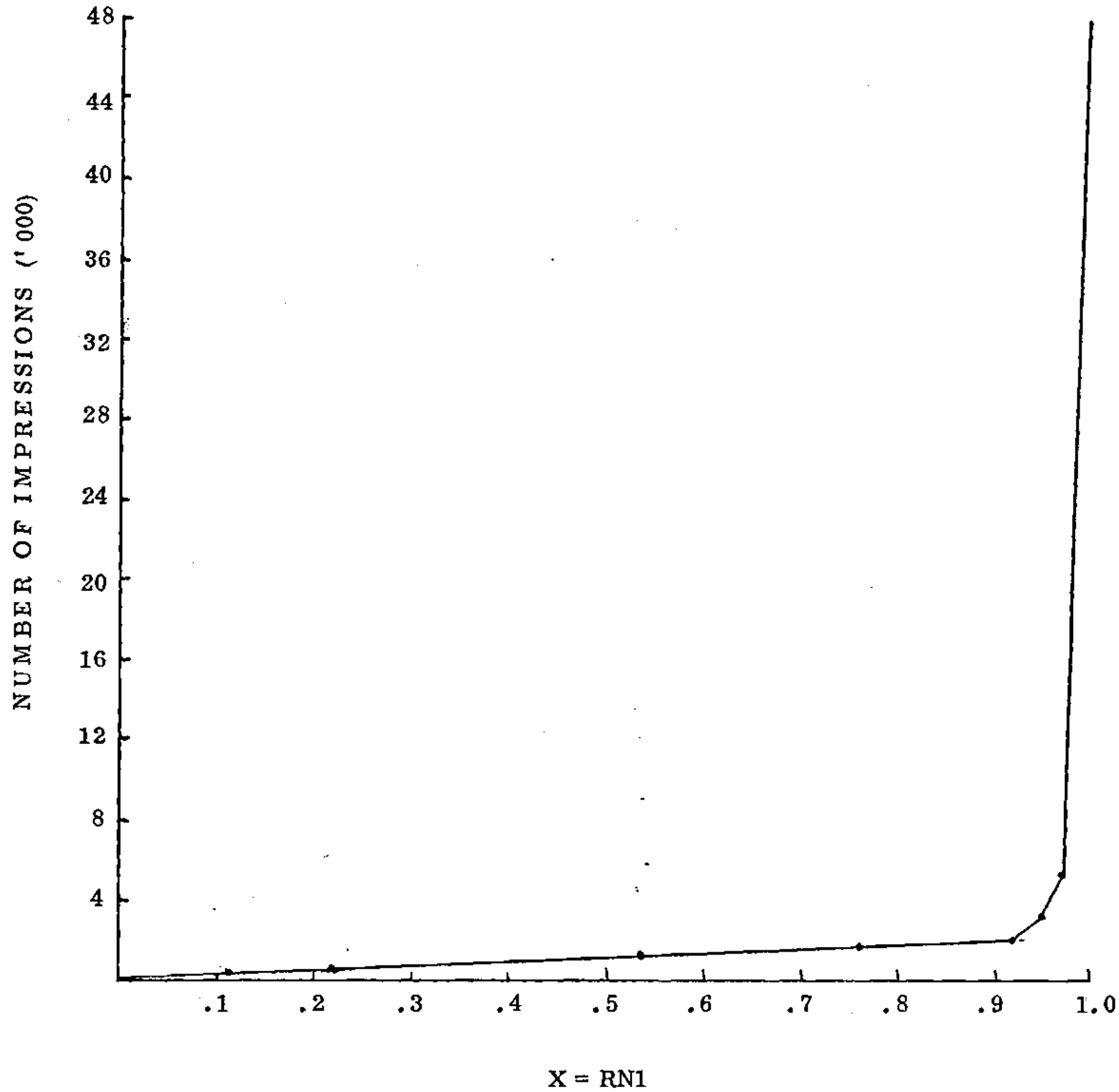
FUNCTION 3--NUMBER OF IMPRESSIONS



FUNCTION 4 -- SIZE OF IMPRESSIONS

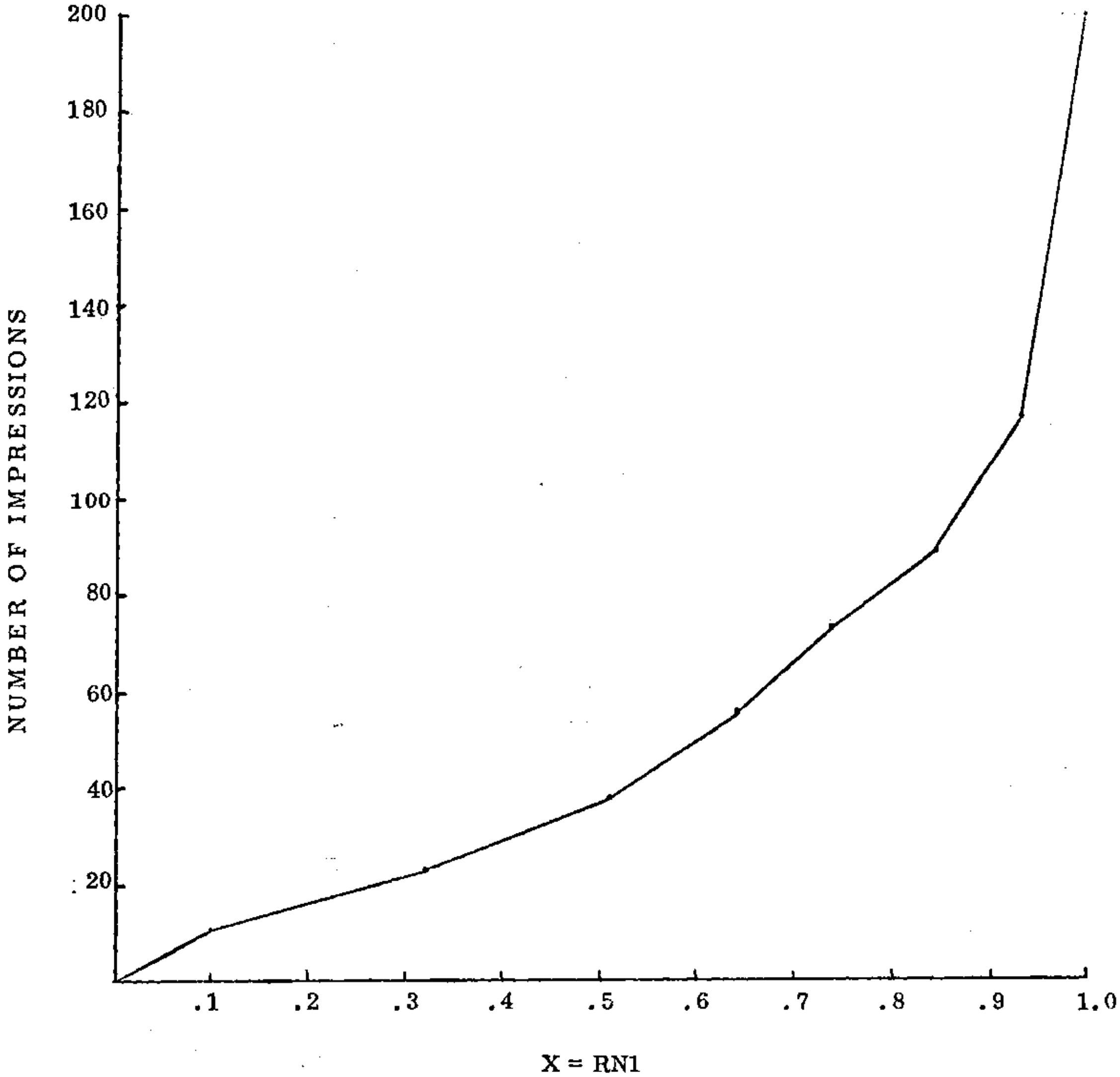


FUNCTION 5--QUALITY OF IMPRESSIONS



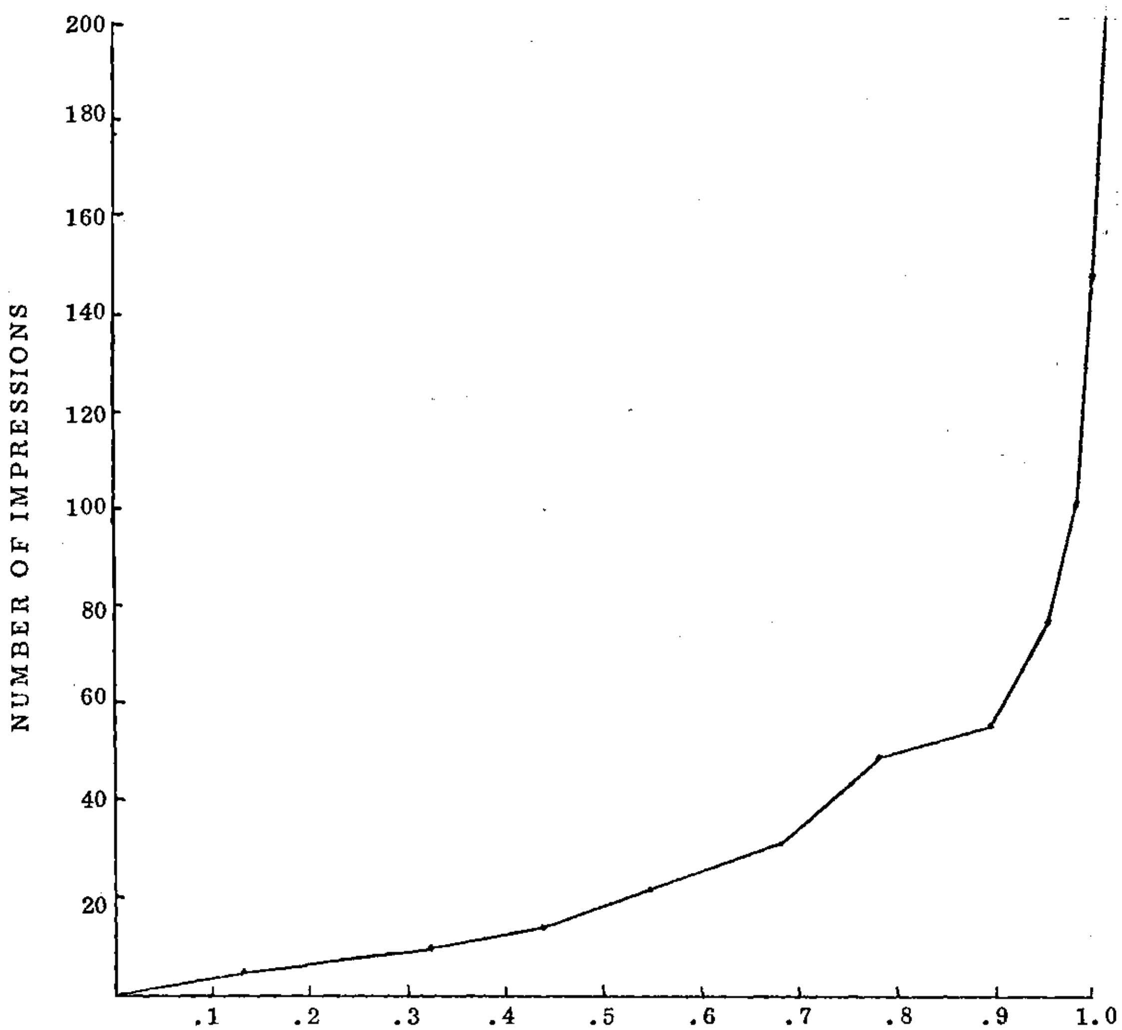
FUNCTION 6--NUMBER OF IMPRESSIONS PER

MASTER PLATE FOR LOW QUALITY

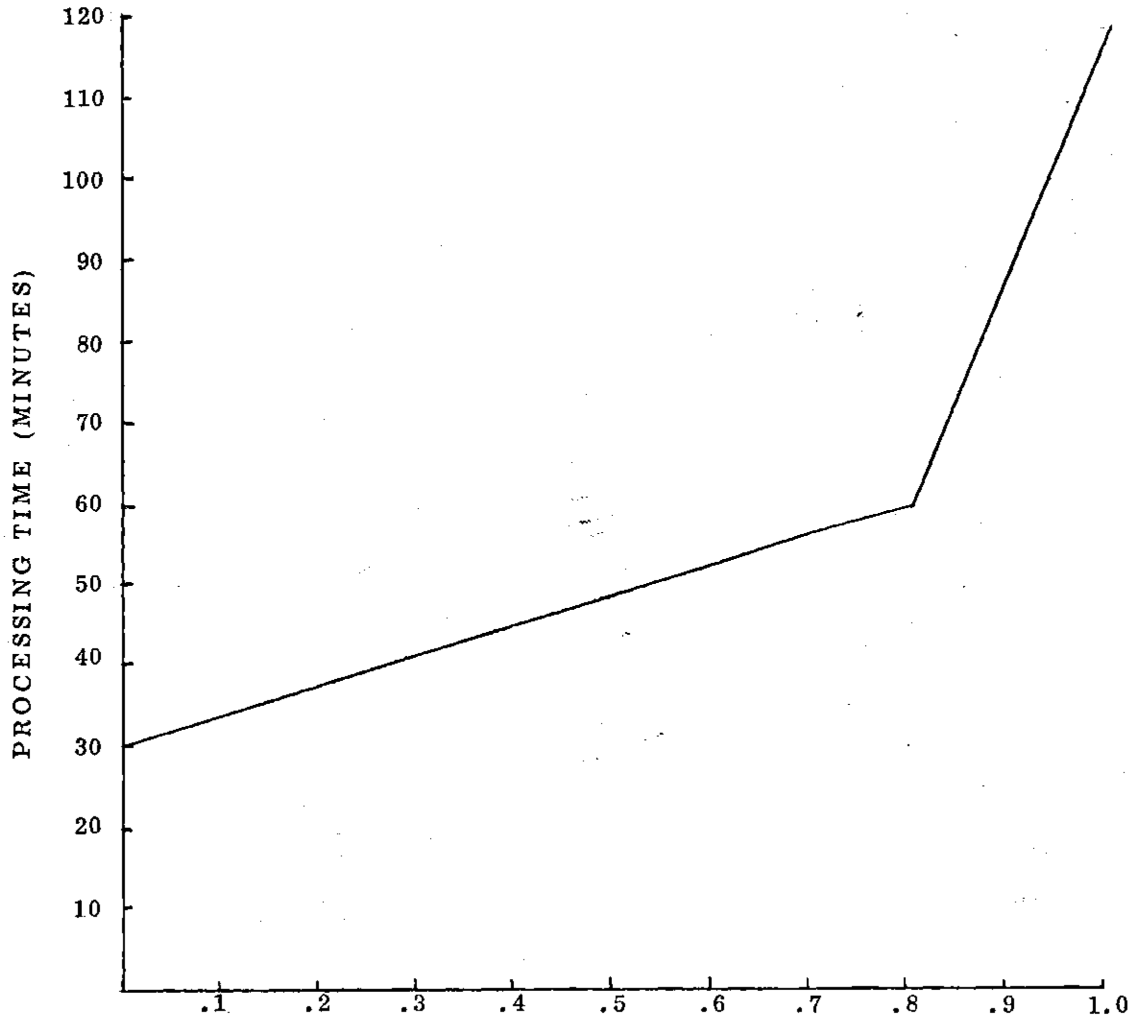


FUNCTION 7--NUMBER OF IMPRESSIONS PER MASTER

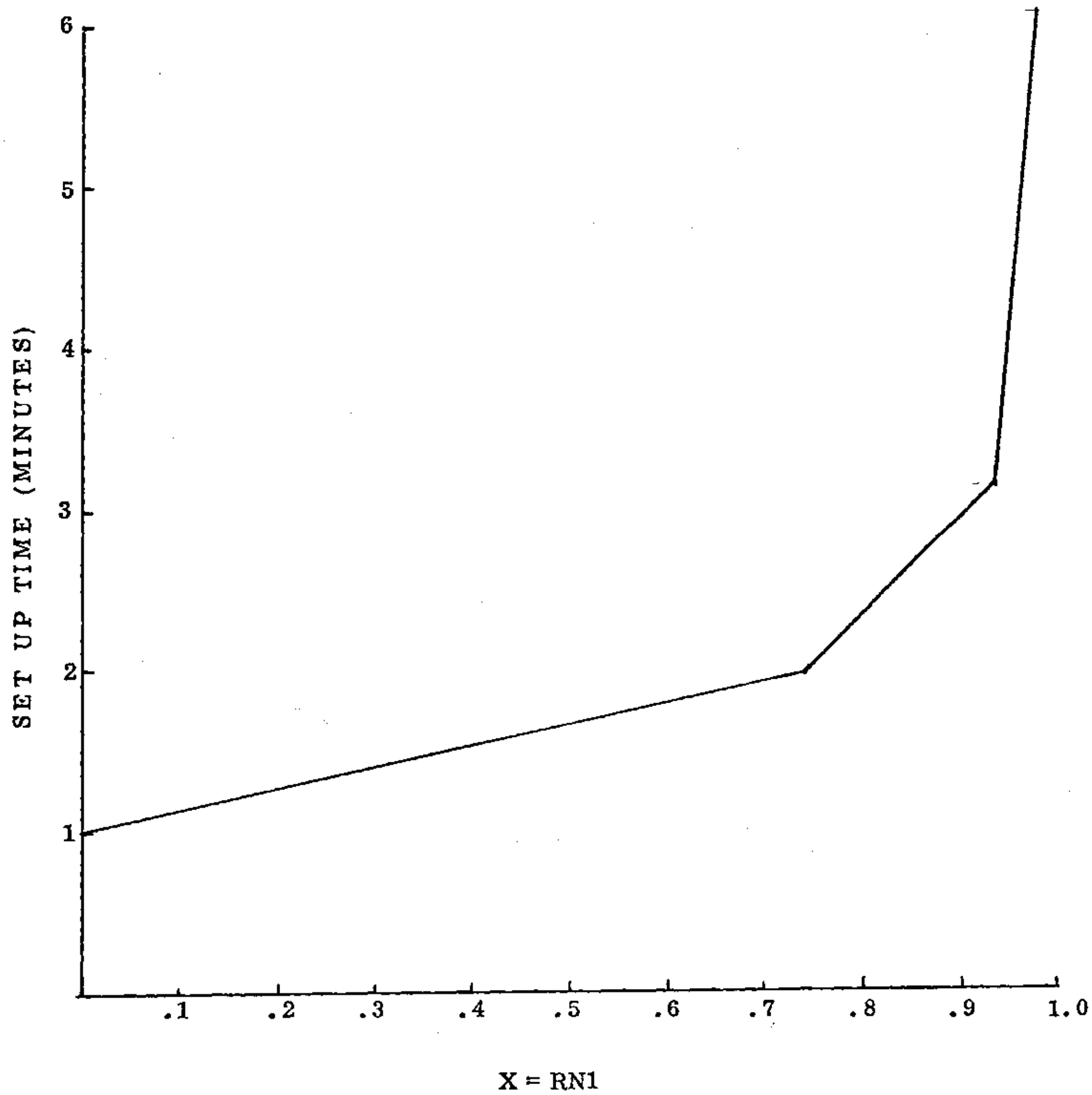
PLATE FOR MEDIUM QUALITY



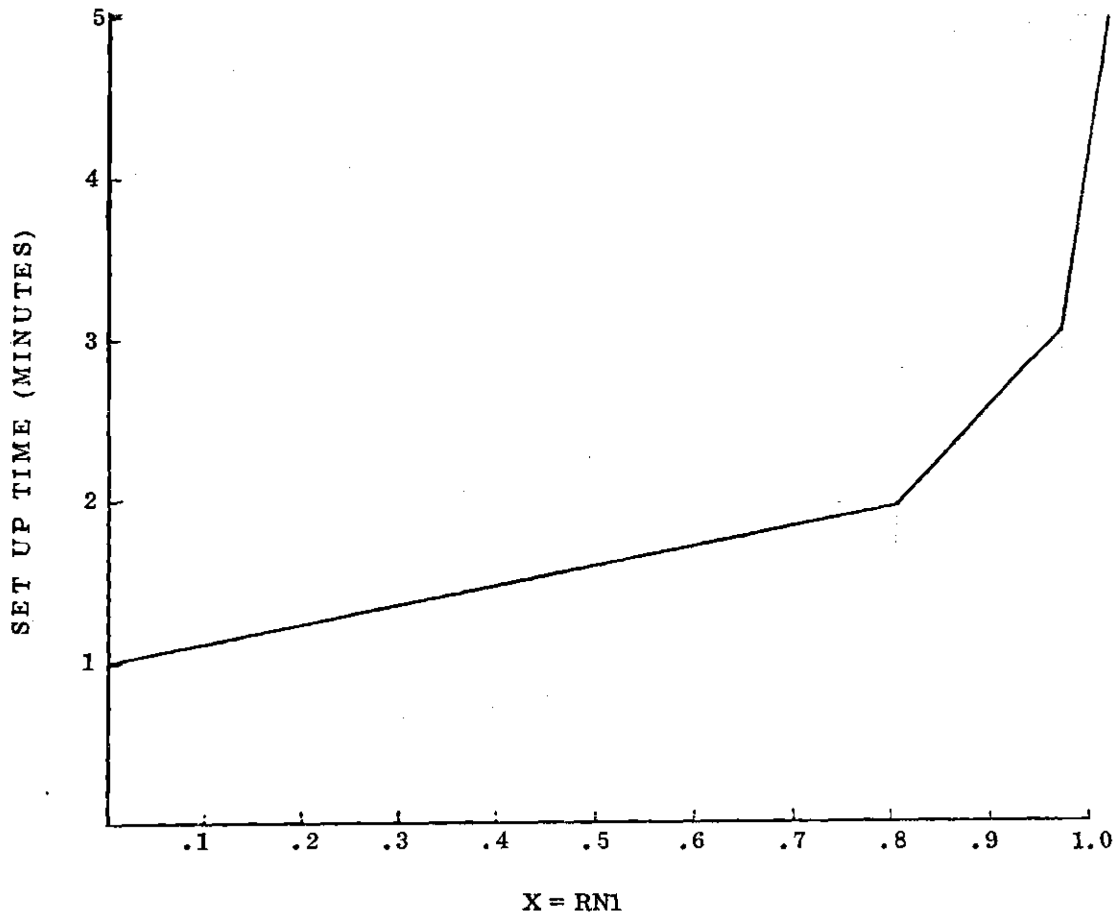
FUNCTION 8. NUMBER OF IMPRESSIONS PER MASTER PLATE FOR HIGH QUALITY



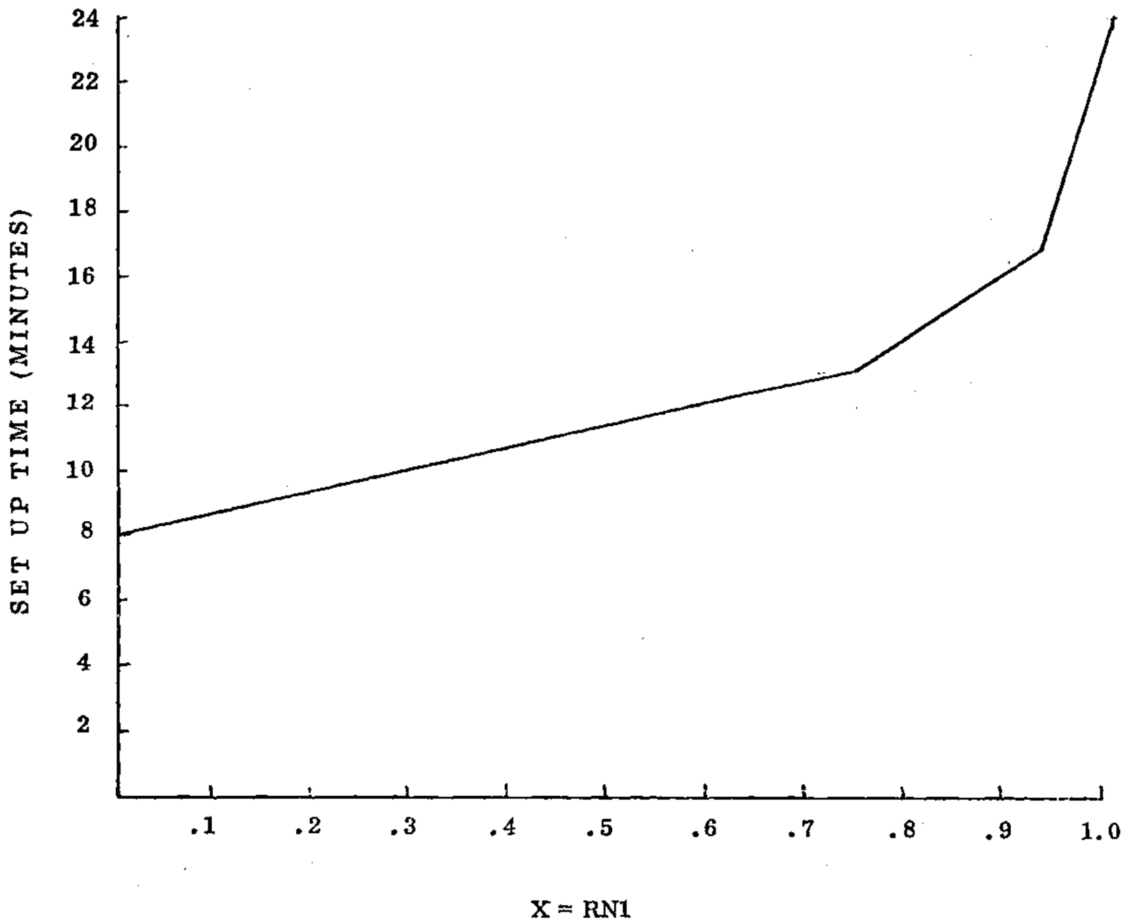
FUNCTION 9--PROCESSING TIME FOR A METAL MASTER PLATE



FUNCTION 10--SET UP TIME FOR A HIGH QUALITY PRESS



FUNCTION 11--SET UP TIME FOR MEDIUM AND LOW QUALITY PRESS



FUNCTION 12--SET UP TIME FOR COLLATING MACHINE

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